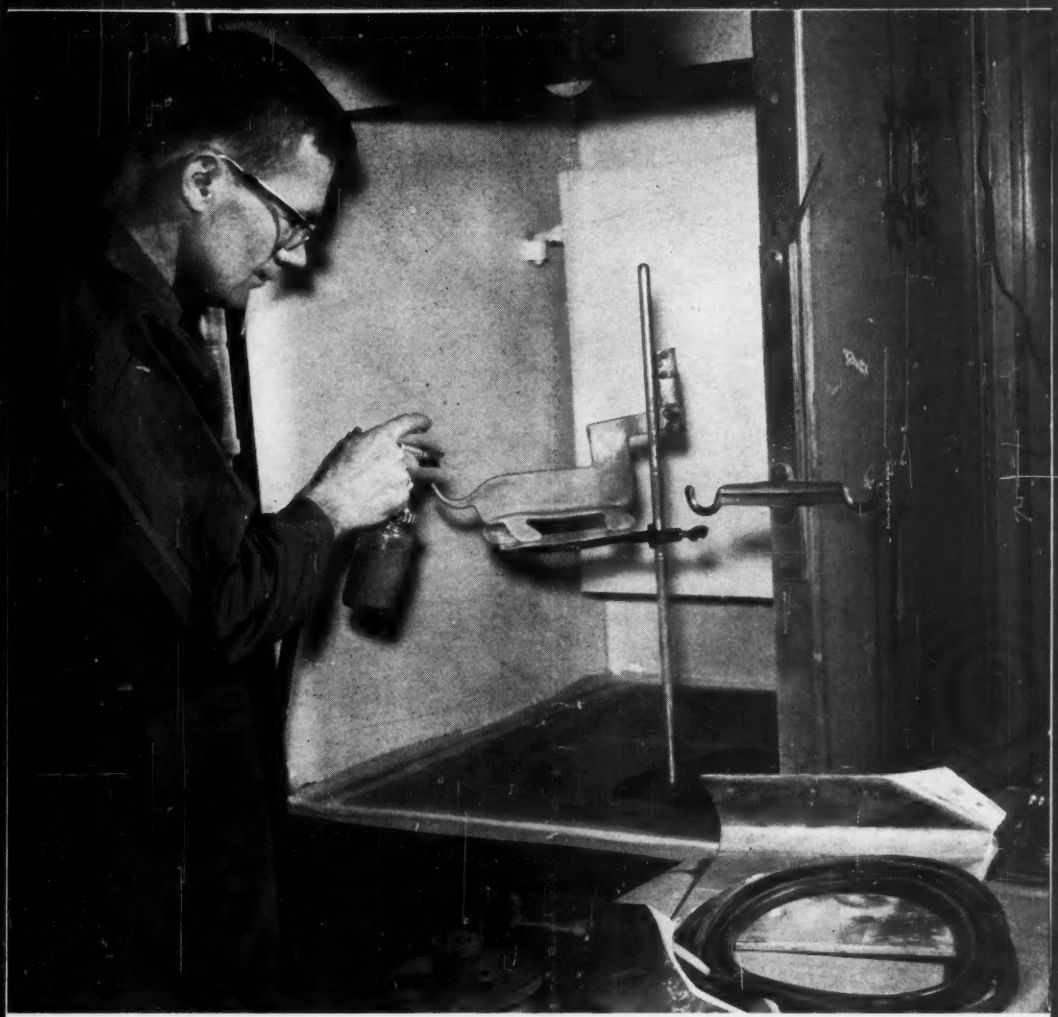
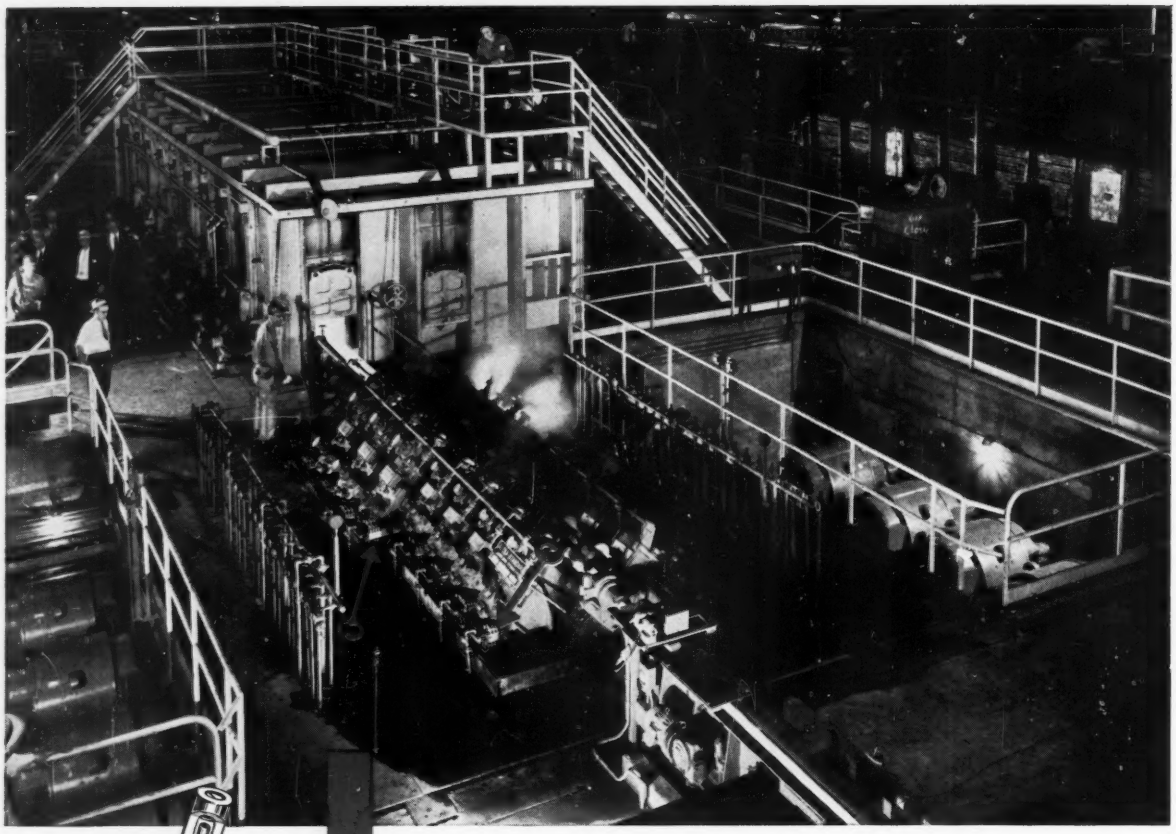
LUBRICATION ENGINEERING

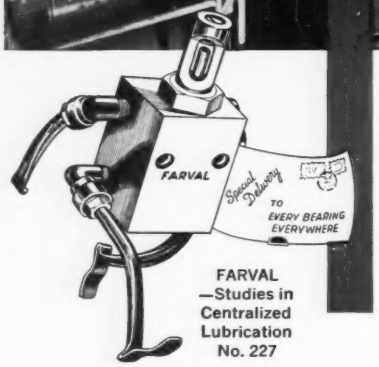
DESIGN RESEARCH APPLICATION EDUCATION MAINTENANCE



Spraying Tetrafluoroethylene Resin (see Cover Story p. 501)

JOURNAL OF THE AMERICAN SOCIETY OF LUBRICATION ENGINEERS





FARVAL
—Studies in
Centralized
Lubrication
No. 227

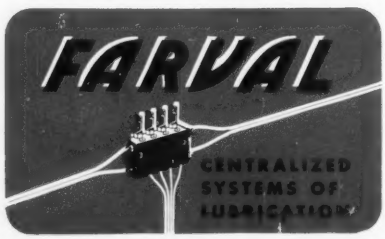
Farval protects bearings as tubing is reduced from 7 to 2 inches

ON this 16-stand Aetna-Standard tube stretch reducing mill, bearings take tremendous pressures as cherry red tubing is reduced from 7 to 2 inches in diameter. And lubricating those essential components is a Farval centralized system delivering measured amount of lubricant at set intervals to every bearing. These bearings are lubricated automatically and safely while the mill is actually in operation.

For bearing protection on your machinery, check with Farval for lubrication. For specifications and drawings, ask for Bulletin 26-S. Write The Farval Corporation, 3267 East 80th Street, Cleveland 4, Ohio.

KEYS TO ADEQUATE LUBRICATION

—wherever you see the sign of Farval—familiar valve manifolds, dual lubricant lines and central pumping station—you know a machine is being properly lubricated.



Affiliate of The Cleveland Worm & Gear Company, Industrial Worm Gearing. In Canada: Peacock Brothers Limited.

Volume 14, No. 12
December, 1958

Lubrication Engineering

DESIGN RESEARCH APPLICATION EDUCATION MAINTENANCE

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Cryopumping Helps Missile Research

An unconventional technique for producing extremely high vacuums which promises substantial savings for research and industrial uses is being employed for missile research in a University of Southern California wind tunnel. The technique, called cryopumping, was explained to members of the American Vacuum Society attending the Third National Vacuum Symposium in San Francisco.

Cryopumping produces such a low temperature that all of the air in a chamber or wind tunnel freezes to a solid, leaving a high vacuum. Details of the technique were given by Bruce M. Bailey, of Arthur D. Little, Inc., research and engineering company of Cambridge, Mass. in a paper co-authored with Dr. Raymond L. Chuan, Director of the University of Southern California's Engineering Center. Dr. Chuan developed the first practical, large-scale application of the technique—a hypersonic wind tunnel used to test missile models under high altitude atmospheric conditions. Bailey and his colleagues at ADL developed the cryopump used to freeze air out one end of the tunnel, providing high-speed air flow over the missile models. The wind tunnel was unveiled only last week.

Gear Symposium Set for Chicago

The important relationship between modern gear design and gear lubrication will be the theme of the First Annual ASLE Gear Symposium to be held in Chicago on January 26-27, 1959. The Gear and Gear Lubrication Committee of the American Society of Lubrication Engineers announces the Morrison Hotel in Chicago to be the site of this first symposium specifically planned to add to the knowledge available to the field of gear design and gear lubrication.

The symposium will be devoted to three principal areas of discussion. These are: spur gear lubrication, extreme pressure lubricants and hypoid gearing, and boundary lubrication. Twelve papers will be presented at four planned sessions. These papers will be presented by some of the country's outstanding specialists in the field of gear lubrication. Among them will be Earle Ryder,, winner of the 1958 ASLE National Award, whose paper is entitled "The Gear Rig as an Oil Tester."

A detailed program and advance registration form appears below.

One Billion Pounds Lubricating Greases Produced in 1957

The lubricating grease industry in the United States produced more than a billion pounds of lubricating greases and fluid gear lubricants in 1957, according to figures just released by the National Lubricating Grease Institute.

Breakdown of lubricating greases made by soap types were limited to six categories and the grand total of lubricating greases shown was 581,879,828 pounds. Fluid gear lubricants were not subject to a breakdown and the grand total shown was 473,999,270 pounds. Eleven companies reported production of less than one million pounds while 14 firms showed production of one to five million pounds. A total of 23 firms reported production of over five million pounds in the lubricating grease category.

ASLE GEAR SYMPOSIUM—MORRIS ON HOTEL—JANUARY 26 & 27, 1959

Monday, January 26, 1959

8:30 AM Registration
10:00 AM to 12 noon

Session I Spur Gear Lubrication I

Chairman—R. K. Nelson, Chief Engr., Eppi Precision Prod. Co., Clarendon Hills, Ill.

"Gear Lubrication—The Known and the Unknown"
by Al Hundere, ALCOR, Inc.

"Gear Lubricants and Lubrication"
by F. Richardz, Westinghouse Elec. Co.

"The Gear Rig as an Oil Tester"
by Earle A. Ryder, Consulting Engineer

2:00 PM to 5:00 PM

Session II Spur Gear Lubrication II

Chairman—L. J. Collins, General Electric Co., Lynn, Mass.

"The Effects of Lubricants on Gear Tooth Scuffing"
by P. M. Ku and B. B. Baber, Southwest Research Institute

"Recent Developments in the Lubrication of Heavy Duty Gearing"
by G. P. Maurer, Falk Corporation

"Efficiency of Involute Spur Gears"
by E. E. Shipley, General Electric Co.

Tuesday, January 27, 1959

8:30 AM Registration
9:00 AM to 12:00 noon

Session III E. P. Lubricants & Hypoid Gearing

Chairman—L. L. Withrow, General Motors Research Staff, G.M.C., Detroit, Mich.

"A Laboratory Rating Method for EP Lubricants"
by A. J. DeArdo and L. B. Sargent, Jr., Aluminum Co. of America

"Analytical Study of Surface Loading and Sliding Velocity of Automotive Hypoid Gears"
by D. L. Powell and H. R. Barton, Armour Research Foundation

"Limited Slip Differentials"
by L. J. O'Brien, Dana Corporation

2:00 PM to 5:00 PM

Session IV Boundary Lubrication

Chairman—W. E. Campbell, Consultant, AFRAM, Cleveland, Ohio

"Apparent Viscosity of Lubricant Films under Very Low Shear Rates"
by E. K. Gatcombe, Prof. Mech. Eng., U.S.N.P.G. School, R. P. Hunnicutt, Dalmo Victor Co., and G. F. Kinney, Prof. Chem. Eng. U.S.N.P.G. School

"Improved Phosphorus-Nickel Alloy Coating for Lubricated Wear Resistance under Severe Conditions"
by J. R. Young, Western Gear Corp.

"Wear in Heavily Loaded Lubricated Surfaces Subjected to Oscillating Motion"
by J. F. Batter and F. E. Reed, Technical Operations, Inc.

American Society of Lubrication Engineers
84 East Randolph Street
Chicago 1, Illinois

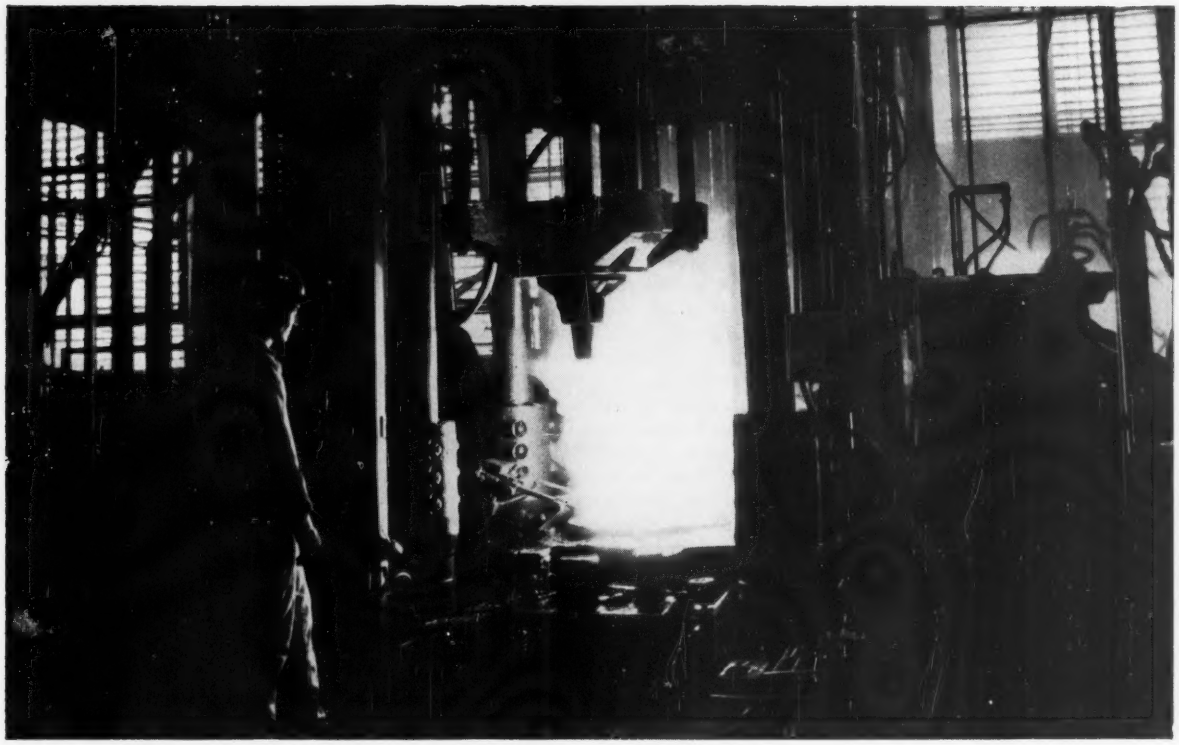
Name_____ **Title**_____

Company_____

Address_____

City_____ **State**_____

General registration $15.00 **ASLE Members $10.00**
Check enclosed ☐ **I will pay at first session** ☐



AT A FAMOUS ORDNANCE PLANT IN NORTHERN LOUISIANA:

600-Ton Lubrication Job for Cities Service!

The huge 600-ton press above is one of several at a well known Louisiana ordnance plant operated by the Remington Rand Division of Sperry Rand Corporation.

A big machine, it naturally poses a big lubrication job... but not so big that Cities Service Pacemaker Oil can't take it in stride. With unusually high viscosity index and superior fortification against oxidation, corrosion and rust, Pacemaker is a natural for the task.

Likewise, throughout the various stages of producing artillery shells—the end product—Cities Service lubricants are hard at work.

Clearly, there's little room for error here—either in the product itself or in the machines that make it. That's why Cities Service lubricants were chosen . . . and it's an equally good reason for making them *your* choice.

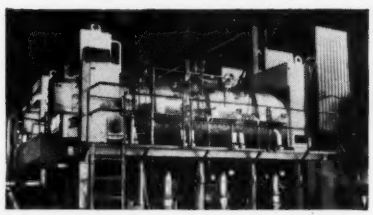
For a survey of your plant's lubrication needs, talk with a Cities Service Lubrication Engineer. Or write: Cities Service Oil Company, Sixty Wall Tower, New York 5, N. Y.

HOW THE ORDNANCE PLANT USES CITIES SERVICE LUBRICANTS

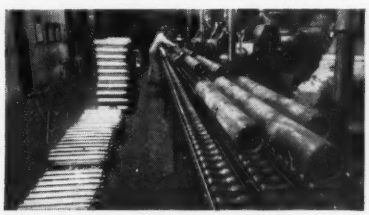
MACHINE	LUBRICANT
Large presses	Pacemaker 3 Hydraulic Oil
Airlines	Pacemaker 1
Speed reduction units	Pacemaker 6
Worm gear reduction units	Optimus 6
Package compressor units	Pacemaker 5
Metal working machines requiring a water soluble cutting oil	Chillo A
General Lubrication	Trojan Gear Oils, Trojan H-2 Grease

CITIES SERVICE

QUALITY PETROLEUM PRODUCTS

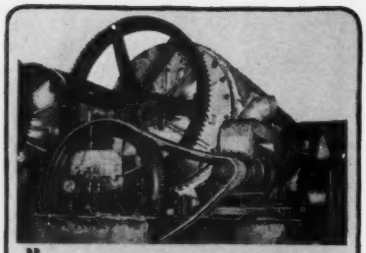


High Speed Gas Furnace heats steel to 2660 degrees F. All lubrication is supplied by Cities Service products.



Partially Finished Shells await final forming. Unusual number of forming operations are required to produce final product.

Forming Press does final forming of artillery shells. The press is lubricated by Cities Service Pacemaker Hydraulic Oil.



"THIS LUBRICANT INCREASED CHAIN LIFE 4 TIMES"

—says FASTERFAT, Division of National Sea Products Limited

"Two years ago we switched from the lubricant we were then using to your LUBRIPLATE, and we are pleased to inform you that we have had very excellent satisfaction from its use. High speed silent chains on the drives of our fish meal cookers, which were formerly worn out in about six months, are still in service after two years."

REGARDLESS OF THE SIZE AND TYPE OF YOUR MACHINERY, LUBRIPLATE GREASE AND FLUID TYPE LUBRICANTS WILL IMPROVE ITS OPERATION AND REDUCE MAINTENANCE COSTS.

LUBRIPLATE is available in grease and fluid densities for every purpose . . . LUBRIPLATE H. D. S. MOTOR OIL meets today's exacting requirements for gasoline and diesel engines.

For nearest LUBRIPLATE distributor see Classified Telephone Directory. Send for free "LUBRIPLATE DATA BOOK" . . . a valuable treatise on lubrication. Write LUBRIPLATE DIVISION, Fiske Brothers Refining Co., Newark 5, N. J. or Toledo 5, Ohio.

NEW PRODUCTS

NEW STAINLESS STEEL FOR HOSE FITTINGS

Missile and jet aircraft programs are now depending on a new stainless steel for use on new hose fittings on flexible fuel and hydraulic lines. The new end couplings, which are reusable and have a special self energizing metal-to-metal seal, make the cable line safer and more secure. Resistoflex Corporation of Roseland, New Jersey, developed the special triple-lock fitting, and specified allegheny Ludlum Steel Corporation's AM-355 stainless steel. The special ring of AM-355 can be easily locked into position, and gives a positive grip on the braid of stainless steel which sheathes the hose tube. With stainless steel, the fixture can be used in corrosive areas, under high pressures (has been tested well beyond the 1500 psi it is expected to withstand), and temperatures up to 500 degrees F. Other uses include steam and hot paint spray applications for industrial use. Resistoflex reports that the hose can be used on the new, exotic missile fuels, and with jet aircraft fuels, oils, hydraulic fluids. Under test conditions the threaded lock ring did not distort even when over tightened. Vibration, the plague of former reusable coupling designs, has no effect on this new design. AM-355 is a special precipitation hardening stainless steel developed primarily for the aircraft industry. This recent member of the stainless family provides the unique combination of strength, toughness, ductility and corrosion resistance necessary for the Resistoflex design. Coupling sizes are from ⅜-inch to 1-½-inch, and to the aircraft hydraulic engineer are designated dash-4 to dash-24.

SPRAY-ON LUBRICANT

The Bel-Ray Company's Molylube lubricant will now be available in a new, easy-to-handle aerosol spray can. The new package will contain a specially compounded dispersion of a micro-fine molybdenum-disulfide known as Molylube 16 micro-fine. The carrier in the lubricant is non-toxic, non-corrosive, non-inflammable and free of any abrasive impurities or resins. As a spray, Molylube is an excellent dry solid film lubricant since the particle size of the MOS_2 is less than one micron. It will resist the attack of most acids and is an excellent lubricant from —100°F. to +750°F. Molylube can be applied directly to any clean surface, especially individual parts prior to final assembly, since it deposits a uniform film of the purest Molylube powder commercially available. A bearing's coefficient of friction is reduced to that of the MOS_2 itself. The lubricant can withstand pressures of over 100,000 psi. For further information, write to Bel-Ray Company, Inc., Madison, N. J.

GRAPHITE BURNER BEARINGS

Large size graphite burner bearings for sawdust burners and similar types of incinerators, thoroughly field tested and used in actual lumber mill operations for more than two years, have been announced by the Joseph Dixon Crucible Company. While designed primarily for the "hot" end of conveyors used in the lumbering industry to carry sawdust and other types of refuse into the burner, these burner bearings are also suitable for conveyor belts carrying refuse and similar materials to other types of incinerators where high temperatures are encountered. They provide efficient, long lasting and automatic self-lubrication at temperatures ranging from 1,200 to 1,500F. Dixon B-19 graphite bearings are custom made, since nearly all refuse burners require different inside and outside diameter dimensions and have variable lengths. For further information, write to the Molded Products Division, Joseph Dixon Crucible Company, Jersey City 3 N. J. Ask for: Product Data Sheet #320-PDS 320.

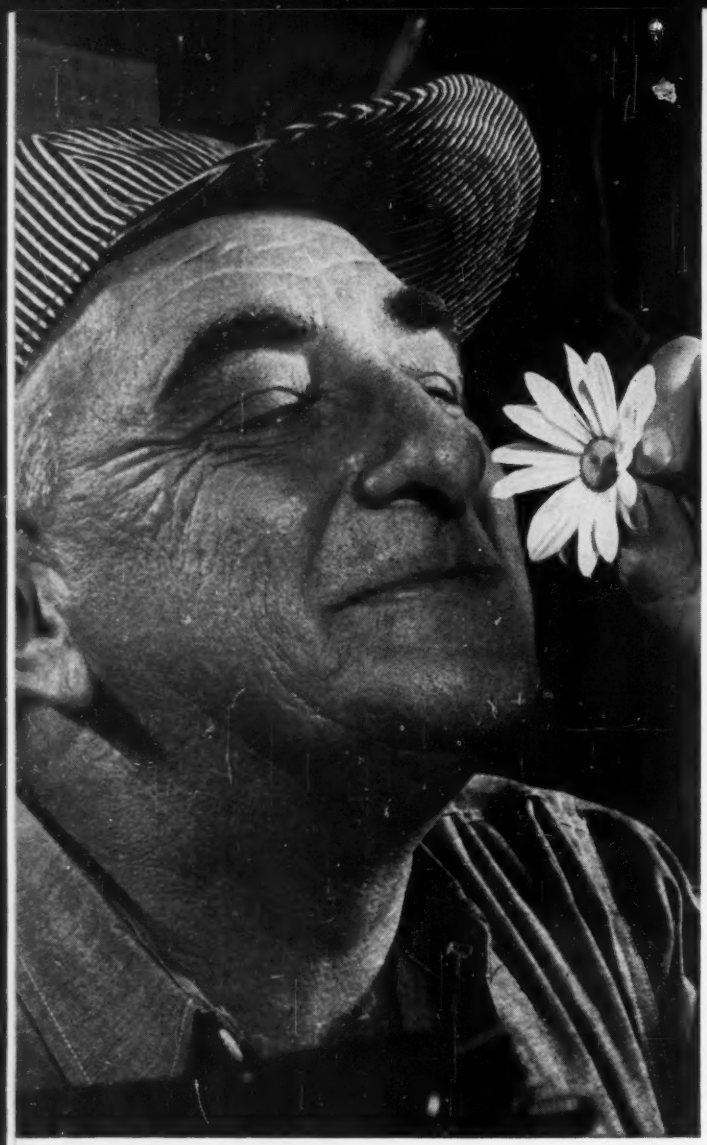
LUBRICANTS IN TUBES

Lehigh Chemical Company, of Chestertown, Maryland, has announced the availability of any or all MIL SPEC Oils and Greases in ¾ ounce unbreakable polyethelene tubes. This new packaging concept will aid in the use and storage of lubricants. Each tube has a self-contained applicator tip which can be used for drop or stream application. Waste and spillage reportedly are eliminated with this applicator tip. Wherever small amounts of lubricants are required, such as in instrument manufacture, miniaturized assemblies, etc., Anderol tubes will simplify lubrication procedures and cut operation costs. Use of these handy tubes will eliminate loss of lubricant due to transfer from bulk storage and also eliminate messy containers and applicators. The tubes are easily stored and dispensed from the parts and supply section and the standard packaging facilities complete inventory control. The complete line of Anderol Lubricants are also available in this packaging for industrial use. For additional information, write or call Lehigh Chemical Company, Chestertown, Md.

DISCOVERED!

...new way to keep cutting fluids as fresh as a daisy!

SEE NEXT TWO PAGES



DISCOVERED...A NEW WAY TO KEEP COOLANTS FRESH AS A DAISY!

Shop tests show ELCIDE 75 keeps cutting fluids fresh longer than ever before

Now . . . there's a new and better way to control the harmful bacteria that cause oil-water emulsion breakdown, acidic corrosion, and rancid odor. It's Elcide 75 . . . a product directly related to one of the most powerful bacteria killers used in medical science today . . . a material that has proved itself in the exacting field of surgical practice and has now been adapted to solve the problem of bacterial growth in soluble oil emulsions.

A large Midwestern manufacturing plant tested Elcide 75 under actual job conditions.

They found that one ounce of Elcide 75 added to each 4 gallons of oil-water emulsion . . .

extended useful life of the emulsion 5½ times . . .

greatly reduced cutting oil requirements . . .

delayed odor and emulsion break for 22 weeks, while untreated machines had to be dumped at the end of four weeks . . .

proportionately reduced down time for recharging . . .

was safe and nontoxic . . .

eliminated bacterial slime and reduced acidic corrosion . . .

drastically reduced their disposal problems.

WHAT ELCIDE 75 CAN DO FOR YOU

This combination of inhibitors can extend the life of your oil-water emulsions 2 to 4 times, or more, and can dramatically cut your oil-concentrate purchases. At the same time, production will increase because you have less down time for recharging.

ELI LILLY AND COMPANY · AGRICULTURAL AND INDUSTRIAL PRODUCTS DIVISION
INDIANAPOLIS 6, INDIANA
TELEPHONE: MELROSE 6-2211

This is one of the causes of emulsion trouble. These are *Pseudomonads*, one of the many harmful types of bacteria found in oil-water emulsions. These, and other bacteria, enter emulsions through the air, water, and plant debris. They set the stage for a chain reaction which causes odor, corrosion, and costly emulsion breakdown.

Prior to Elcide *75*, no single inhibitor was able to control the full range of bacterial growth. Certain of these bacteria quickly develop resistance to single inhibitors and continue to flourish. Now, Elcide *75* controls a wider range of bacteria because it is an effective combination of bactericidal agents. This has been proved in shop tests.

In certain areas where waste-oil disposal is a problem, the use of Elcide 75 proportionately reduces the size of the problem.

Elcide 75 also contributes to better products and longer machine-tool life. Bacterial contamination causes acidic decomposition of the emulsion and sets up conditions for corrosion. By controlling the bacteria, you eliminate this source of trouble.

Employees like Elcide 75 because, when added to the emulsion, it is completely safe. In another recent test involving over 1000 machines, it was shown that Elcide 75 was safe, nontoxic, and harmless to sensitive skin. It also reduces the chance for bacterial infection caused by contaminated emulsion.

YOU KNOW WHAT YOU GET WHEN YOU BUY ELCIDE 75

With Elcide 75, you know you have the proper amount for effective treatment because you add it to your emulsions right in your plant. The standard recommendation is one ounce of Elcide 75 per 4 gallons of oil-water emulsion.

PROVE IT TO YOURSELF... TRY ELCIDE 75 IN YOUR PLANT

The best way to determine the value of Elcide 75 is to try it under your normal plant conditions, using your regular oil-water emulsion. After you've had an opportunity to compare results, we believe you'll agree that Elcide 75 is a valuable discovery that will greatly increase your plant efficiency.

PRODUCT SPECIFICATIONS ELCIDE 75

(Lilly's brand of bactericide for cutting fluids)

Active Ingredients—Thimerosal (Sodium Ethylmercuri Thiosalicylate) and Sodium o-phenylphenate.

Package	Price per Gal.
1-gallon polyethylene . . .	$8.50
5-gallon polyethylene . . .	$8.00
55-gallon stainless steel . . .	$6.50

Terms: 1%, 10th prox.; net, 30th prox. F.O.B. Indianapolis. Transportation paid via carrier of our selection.

For further information or to place your order, phone or write.

ELCIDE 75™

PATENT PENDING

Lilly

NEW EMOLEIN® 2910 LOWERS COST OF SYNTHETIC LUBRICANTS

Emolein 2910 Lubricant Ester, formerly designated Emery 3033-S, is the answer to lower-cost synthetic fluids and greases required by the jet age. In synthetic fluids, total cost can be reduced substantially by blending Emolein 2910 with an azelate diester without sacrificing performance. In greases, Emolein 2910 can be used alone or by blending with other fluids.

Emolein 2910 dipropylene glycol dipelargonate is a new type of diester based on inexpensive pelargonic acid. With performance testing having confirmed its utility, it joins the established members of the Emolein line of diesters, Emolein 2957 di-iso-octyl azelate and Emolein 2958 di-octyl azelate, whose performance under the conditions encountered in modern jet engines has given them a recognized position in the synthetic lubricant field.

One more important fact: The Emolein esters are *not* dependent upon imported raw materials. Since they are derived from abundant domestic tallow their future supply is practically unlimited. For more detailed information on Emolein 2910 or the Emolein azelates, return the coupon below.

Emery Industries, Inc., Dept. Y-12
Carew Tower, Cincinnati 2, Ohio
Please send bulletins:
☐ No. 411 (Emolein 2910 Pelargonate)
☐ No. 409A (Emolein Azelates)

Name_____ Title_____
Company_____
Address_____
City_____ State_____

Emery

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Export Department: Carew Tower, Cincinnati 2, Ohio

COVER STORY

The established properties of tetrafluoroethylene (TFE) resins are finding an increasing number of industrial, commercial, military and home applications. These applications have been greatly enlarged with the introduction of Acheson's 'EMRALON,' one application of which is illustrated on this month's cover. So far there are two members in this newest family of Acheson's colloidal dispersions . . . 'Emralon' 310 and 'Emralon' 320.

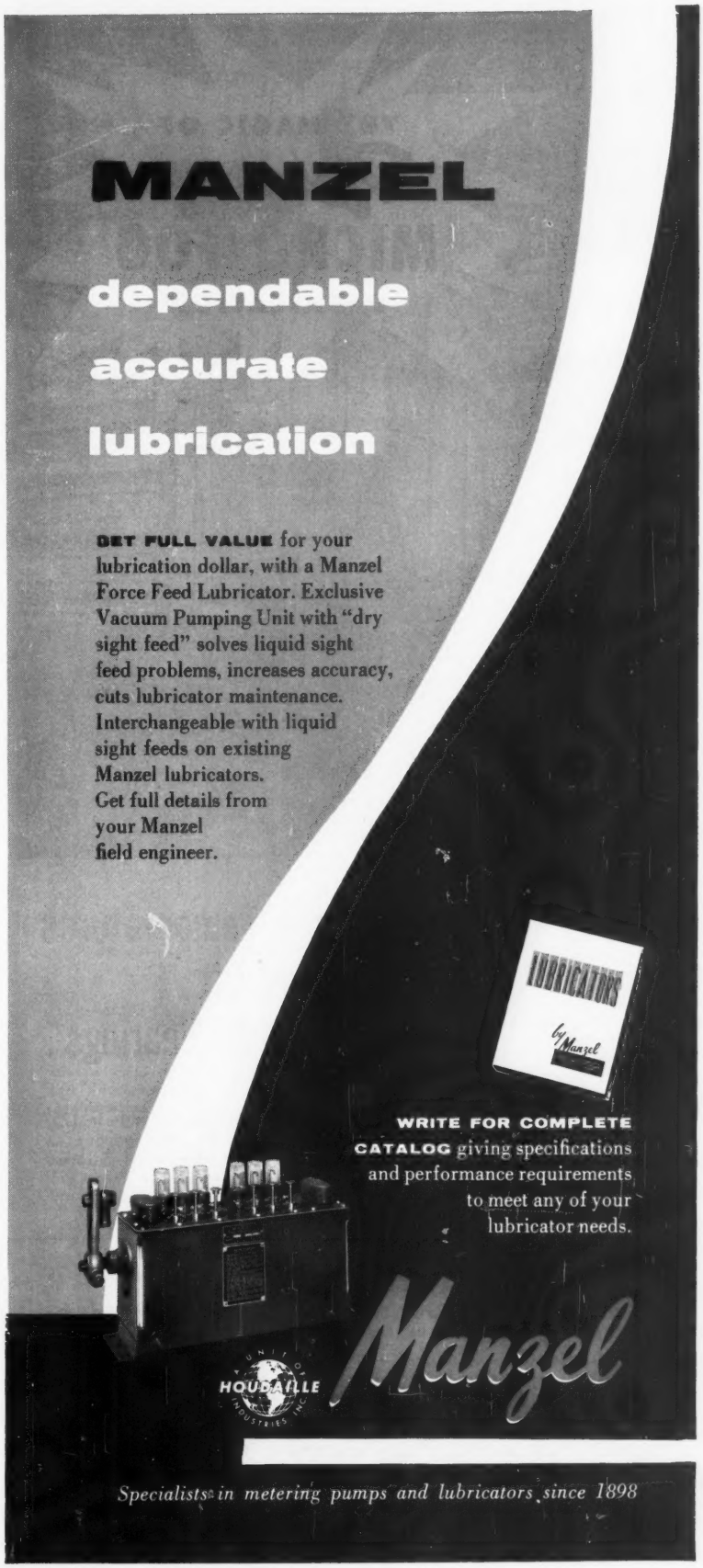
Some of the advantages of TFE that led Acheson into a five year development program include low coefficient of friction, flexibility, chemical inertness, less than 0.01 moisture absorption and excellent durability. In addition, TFE resins are able to withstand temperatures ranging from —450°F. through +500°F. or more.

Formerly, the applications of TFE were limited to materials which could withstand the high temperatures necessary for sintering—more than 700°F. The new series of dispersions now makes possible curing at 300°F. or even less. Thus a lubricating, corrosion resistant film can be applied to wood, rubber, plastics, light metal and many other heat-sensitive materials.

The illustrated dispersion is composed of specially processed TFE particles suspended in a liquid carrier. To mix, the liquid TFE is slowly added to the binder solution while agitation is provided by a suitable mixer. The result is a smooth dispersion ready for use. Application should be made preferably with a spray gun of the external-atomizing type using air pressures of 35 to 50 pounds per square inch. This is followed by air-drying, or infra-red, or oven curing, depending on the Emralon used.

The normal film thickness for lubricating purposes is about 0.6 mil. Where thicker coatings are desired, multiple passes can be made by the spray gun with air-drying between passes. Properly applied the film is smooth and continuous.

The product designated Emralon 310 is a dispersion of TFE in a phenolic binder. Applied by spray, the dispersion can be cured in one hour at 300 F. and exhibits the low-friction properties of TFE with the durability of the binder. Emralon 320 is air-drying and designed for use on substrates even more sensitive to temperature or for use where baking is not practical.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dependable
accurate
lubrication
GET FULL VALUE for your lubrication dollar, with a Manzel Force Feed Lubricator. Exclusive Vacuum Pumping Unit with "dry sight feed" solves liquid sight feed problems, increases accuracy, cuts lubricator maintenance. Interchangeable with liquid sight feeds on existing Manzel lubricators. Get full details from your Manzel field engineer.
LUBRICATORS
by Manzel
WRITE FOR COMPLETE CATALOG giving specifications and performance requirements to meet any of your lubricator needs.
A UNIT OF HOUDAILLE INDUSTRIES INC
Manzel
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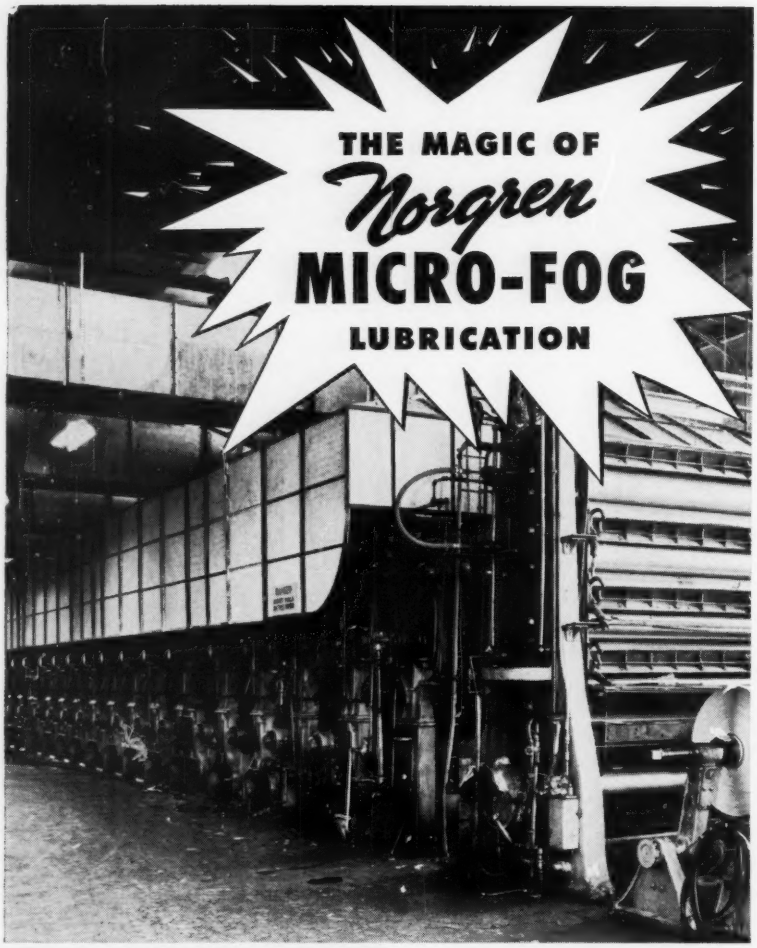

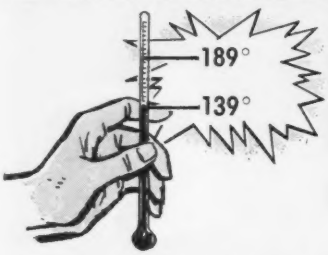

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INDUSTRY NOTES

Socony Patents

Socony Mobil announces plans for a non-exclusive licensing of their recent patents for improved lithium greases. U.S.P. Nos. 2,842,493 and 494, patented July 8, 1958, cover the use of straight lithium and lithium mixed-base greases containing balanced proportions of soaps of wool grease fatty acids and of conventional fatty acids.

These compositions show superior performance, particularly under wet conditions of use where many lithium greases are prone to show excessive breakdown and provide little in the way of rust protection when the grease becomes contaminated with water.

In addition, they are readily compatible with conventional greases and pose no mixture problems. The dropping points of new greases range as high as 400° F and are normally above that of a lithium stearate grease.

Union Carbide To Purchase Texas Plant

Union Carbide Corporation has exercised its option to purchase from Amoco Chemicals Corporation the utilizable facilities which remain on the 306-acre tract at Brownsville, Texas, site of the processing plant formerly operated by Amoco. The option also includes the 42-mile Weslaco-Brownsville natural gas pipeline. Union Carbide is negotiating a long-term lease with the Brownsville Navigation District (Port of Brownsville) for the Brownsville tract.

Engineering studies will be made for additions and revisions at the site. Utilization of these facilities will be deferred for this reason and also will depend upon completion of satisfactory arrangements for fuel gas and raw material supply. Operations at Brownsville will be carried on by Union Carbide Chemicals Company and Union Carbide Olefins Company, both divisions of Union Carbide Corporation.

The project was originally designed and built by Carthage Hydrocol, Inc. to produce synthetic gasoline, other petroleum fractions and co-product chemicals from natural gas by the Fischer-Tropsch process. It was operated by Amoco Chemicals Corporation until last fall. Union Carbide is not contemplating the production of either synthetic gasoline or petroleum products, nor does it intend to produce chemicals by the Fischer-Tropsch process.

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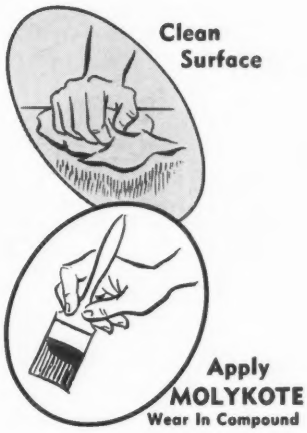

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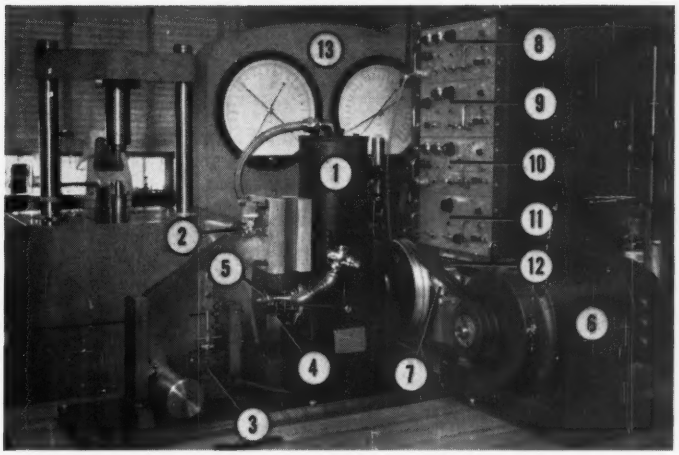
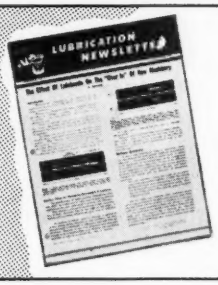


New lubricant testing machine designed for "wear in" tests. The machine maintains a fixed mating path on the specimens; insures uniform load distribution over the contact area; and provides flexibility in producing a variety of wanted conditions, reliability in maintaining them and sensitivity and accuracy in recording. Legend: 1. Oil reservoir, 2. Load pick-up, 3. Friction-force pick-up, 4. Test block, 5. Test ring, 6. Variable speed motor, 7. Generator, 8. Carrier amplifier (for load), 9. Load level pre-amplifier (for temperature), 10. Carrier pre-amplifier (for friction force), 11. d. c. coupling pre-amplifier (for speed), 12. 4-channel recorder, 13. Controls of hydraulic testing machine.



A detailed study of "wear in" lubricants is covered in our new LUBRICATION NEWSLETTER #5, and the MOLYKOTE "WEAR IN" Compound is discussed in Bulletin #120. Send for them today. Address your letter to The Alpha-Molykote Corp., 65 Harvard Ave., Stamford, "Research City", Conn. Phone: FIreside 8-3724.

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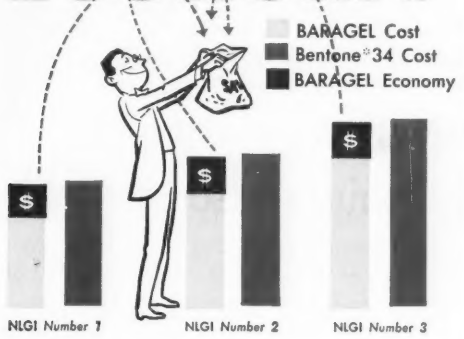

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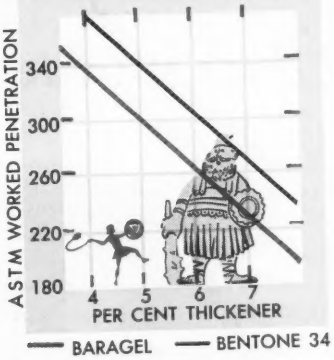

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Lube Lines

by A. F. Brewer*

Co-ordination

The dictionary defines co-ordination as act of co-ordinating; state of being co-ordinate; harmonious adjustment or functioning. "Teamwork" would be another definition for this term when applied to plant lubrication. To go a bit further in our analogy, we might liken the salient participants to an offensive backfield with the lubrication engineer calling the signals from quarterback. His team-mates represent purchasing, engineering and management. The ends take the passes and put the mechanics of lubrication into operation for the desired gains which lead to greater machine efficiency and more assured production.

Some people believe that we are entering an era where greater productivity of available machinery can be considered one of the buttresses or bulwarks to offset inflation. To the credit of the lubrication people, this idea is not new; for years we have preached that high production is a natural consequence of effective lubrication.

INDIVIDUAL RESPONSIBILITIES

But let's come back to the team. With management as captain and fullback there should be a direct line of communication with the quarterback—the lubrication engineer. Then the huddle should include purchasing and engineering as the halfbacks who function in the development of plays by studying the lubrication requirements of the machines and seeing that necessary lubricants are obtained.

Probably our hypthetical team also should include a coach in the person of the consulting lubrication engineer from the lubricant supplier. Naturally he would not appear on the field or in the line-up, but his experience could be invaluable to the team. Usually he has had quite a few seasons of this experience in a wide variety of industries. For example, he can compare the operating conditions which prevail in steel against those in the textile or rubber industries. He can judge the suitability of bearing materials equally as well as he can evaluate the merits of modern lubricating equipment. He is conversant with the modern concept of chemistry as related to lubrication, and he realizes the wisdom of using selected additives to augment the lubricating ability of conventional lubricants. He also understands their ability to provide added resistance to rusting, corrosion and other objectionable results in service.

SKULL PRACTICE

Perhaps our industrial team could profit from the blackboard study routine of the football people. In a sense it would be another way of outlining a schedule of planned lubrication by showing "blown-up" views of lubrication diagrams of the machinery involved. This would enable the lubrication engineer to point out the most important moving parts and to emphasize their co-ordinated relationship to other parts. In effect, teamwork also must be built into the machine if it is to produce dependably and economically.

Skull practice of this nature would impress upon the engineering people that "designing for lubrication" is just as important as "designing for operation." In turn, the purchasing people would realize that "buying lubrication" and dependable production is far more important than just buying lubricants on a price basis. There is no monetary saving if a few dollars saved by purchasing "ordinary" lubricants are frittered away by increased maintenance costs and production time losses.

THE MORAL

In between the lines we must read the responsibility of management throughout this discussion. The rest of the team in any plant can go only so far in developing a beneficial lubrication procedure. They must have the encouragement of management and the acceptance of the relationship of effective lubrication to economical production. Statistics are as valuable here as they are in evaluating any other type of team performance. Again, the lubrication engineer of today has foresight; he can back up a wide range of recommendations going from a simple change from type of lubricant in to an installation of the most intricate lubricating system.

Records speak louder than words. The lubrication engineer can prove to his management that co-ordination and teamwork pay off when the front office is as interested in the economics of lubrication as in tickets for the big game.

* Consultant and author of "Basic Lubrication Practices."

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Vol. 14, No. 12

Lubrication Engineering

new transactions for the new year

Did you ever feel that you had in your possession something so important and so valuable that you wanted everyone to know about it? That's the way that we feel about the new issue of *Transactions*, Volume 1, Number 2.

Of course, we shouldn't be surprised by this feeling. It's exactly the way we felt after the first issue of *Transactions* appeared. We were very proud to publish a volume containing material of such uniformly high quality.

And, after reviewing the advance copies of this, our second issue, we again have nothing but the highest praise for its contents. In fact, we want to shout from the housetops that this issue is so worthwhile that we feel that no industrial company's library is complete without a copy.

We checked through our files and discovered that our Society's members represent 1,000 companies—that's 1,000 issues of *Transactions* that should sell themselves. But since we don't believe that anything can really sell itself, we're providing you with an easy method of obtaining *Transactions*. Your dues statement for 1959 will have a space for ordering this volume.

We're convinced that, once you get your copy of this latest *Transactions*, you'll be as sold on it as we are.

But before you run to fill in that 1959 dues statement, please accept the best wishes of Lubrication Engineering's editorial staff for a healthy and a happy new year.

The Officers and Directors of ASLE take this opportunity to extend to all of Lubrication Engineering's *readers their sincere wishes for a happy and prosperous holiday season.*

Lubricants in the Forming of Aluminum

*by Marco Petronio**

ABSTRACT

A number of lubricants of known composition were evaluated in a laboratory slow-speed draw test by determining the forces obtained during the drawing of a caliber 0.30 aluminum cartridge case. It was learned that conditioning of the aluminum surface prior to drawing is very important and should be considered equally as important as the liquid drawing lubricant. This study therefore includes an investigation of several surface pretreatments such as various pickling and alkali treatments, phosphating, and oxidation by both electrochemical and chemical immersion methods.

Shop test results are reported corroborating laboratory findings in the drawing of 2024, 5052 and 7075 aluminum alloys. There is reported also limited shop test data showing that hot forging and cold extrusion of aluminum are facilitated by the use of an oxide pretreatment.

INTRODUCTION

Although the forces required for the plastic deformation of aluminum are considerably lower than those required for other metals, the problem of lubrication is far more acute. Difficulty is frequently experienced in production forming of aluminum and aluminum alloys due to loading or fouling of the tools, scoring or scratching of the work pieces and sometimes tearing of the pieces.

Bowden (1) reports the coefficient of friction of steel sliding on electrolytically polished aluminum to be 1.2 which is much higher than that obtained with steel sliding on other metals. The coefficient of friction of aluminum on aluminum is reported by Gemant (2) to be 1.4. An inconsistency thus seems to arise since aluminum, like most metals, readily forms an adhering oxide coating and it has been established quite conclusively by many investigators (1,2,3) that metal oxide films serve as lubricating films and substantially aid in reducing friction. The coating however, is thin and hard. The underlying metal being soft and easily deformable causes the oxide film to rupture during a drawing or extrusion process. The discontinuities thus formed in the film cause the aluminum metal to be forced through the openings and weld to the steel tools (die and punch). The aluminum being soft and ductile yields before the forces of adhesion between aluminum and steel are reached. Because of the work hardening characteristics of metals, the portion of metal which is transferred to the tools will have a higher tensile strength than the metal subsequently passing over the tools. Metal transfer becomes progressively larger until it reaches such dimensions that the work is scratched or torn. Under most operating conditions it is possible to minimize this effect with good lubrication but almost never is it completely eliminated.

Early in this work it became apparent that the condition of the aluminum surface is a very important part of the lubricating system and as much emphasis should be given to the study of surface conditioning or pretreatment of aluminum as to the study of the liquid drawing lubricants.

DRAW TEST

The drawing was accomplished in a 20,000 lb capacity tensile testing machine. Standard draw tools were used and measurement was made of the forces required to draw aluminum caliber 0.30 pieces through the fourth draw operation. The rate of travel of the punch through the die was 3 inches per minute. A schematic drawing, Figure 1, illustrates the punch and die setup in the test machine. The punch is held in the top and stationary member of the machine and the die is held on the bottom and movable member. The drawing operation is accomplished by placing a draw piece with lubricant in the guide ring and forcing it through the die with the punch. Five draw pieces processed in this manner constitute one test. An autographic recording device attached to the testing machine produces a plot of draw forces versus time. An idealized form of a typical curve produced by this recording device shows a fairly rapid rise to a peak value, a relatively prolonged descend, and then a slow rise and fall again. Thus, for purposes of visualization, one can consider the curve as consisting

* Frankford Arsenal, Philadelphia 37, Pa.
Recipient of award given by Cleveland Section to best 1958 Annual Meeting metal working lubrication paper.

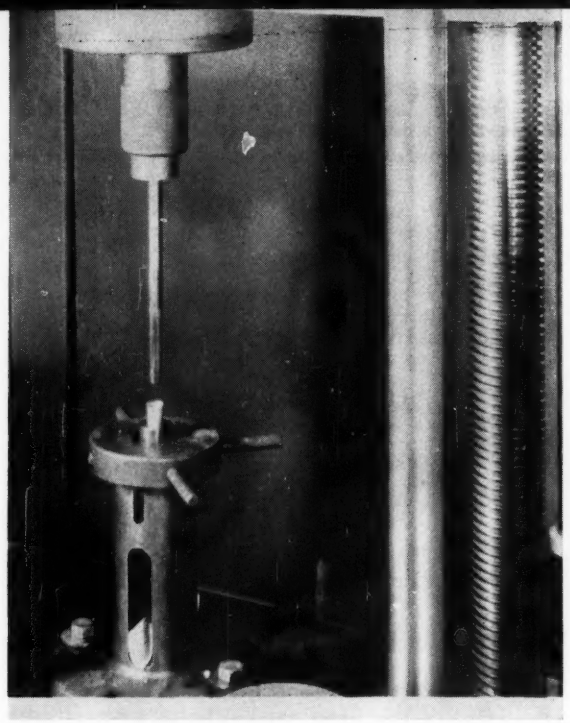

Figure. 1. Setup used for drawing operation.

of two humps with a trough between them; actually, the peak value of the second hump is much less than that of the first hump, and is close in value to that of the bottom of the trough. Nevertheless, this image of a two-humped curve will serve to describe the location of the three points that were selected for calculating the lubrication index; these points were the peak of the first hump, the bottom of the trough, and the peak of the second hump. These points are termed respectively the first maximum force, the minimum force, and the final maximum force. A typical recording, illustrating the location of these three values, is shown in Figure 2. The computed lubrication index, which is the sum of these three forces, established comparative levels of lubrication efficiency. A low value for lubrication index is desirable for it indicates low power consumption and low friction between tool and work.

The average variance, s^2 calculated for the lubrication index of some thirty-five lubricants tested was found to be 20,000. The spread in variance values ranged from 1000 to 204,000. However, 90 per cent of the values were within 1000 and 30,000. Accepting a confidence level of 95 per cent, a difference of about 250 in lubrication index would be significant for 90 per cent of the lubricants.

ALLOYS AND THEIR HEAT-TREATMENT

The draw pieces used at the start of this investigation were made of R303 aluminum alloy. When additional draw pieces were required to perform the remaining tests, it was found that the R303 alloy was no longer available. The only available material being 2024 alloy, it was used in place of the R303 alloy. Both alloys used were clad materials; thus the lubricated surface was that of the cladding material. The chemical analyses of these alloys and the cladding material are shown in Table 1.

A two-part lubricating system was used in the fabrication of the third-draw pieces which were used for this investigation. Prior to drawing, the pieces were coated with a dried-on soap film obtained by immersion in an 8 per cent soap solution maintained at 180 F and then permitted to air-dry. The coated pieces were drawn using a liquid lubricant consisting of a sulfurized fatty oil (SFO) blend.

The following heat treatment was used to restore the draw pieces to the completely soft condition prior to the fourth drawing operation; care was exercised not to use draw pieces which had been heat-treated more than one week prior to conducting the lubrication test:

The R303 alloy draw pieces were heated at 825 F for four hours, quenched in water, and aged at 450 F for four hours, and air-cooled. They were then given an annealing treatment consisting of heating at 750 F for two hours, furnace-cooling at a rate of 50 F per hour to 400 F, and air-cooled.

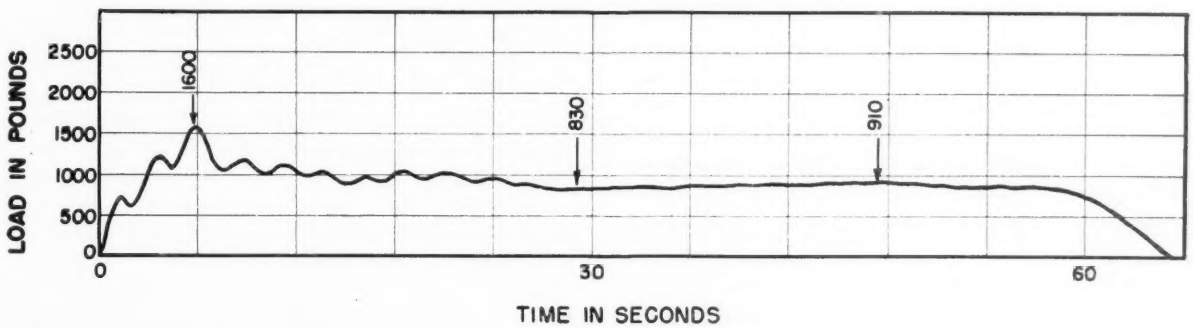

Figure 2. Graphic recording of draw forces showing selection of three points for calculation of lubrication index = 3340 (1600 + 830 + 910 = 3340). Draw piece was electrochemically treated, searic acid coated and drawn with SFO.

TABLE 1. SPECTROGRAPHIC ANALYSES OF THE ALUMINUM ALLOYS USED FOR DRAWING (ALL VALUES ARE MAXIMUM UNLESS OTHERWISE INDICATED.)

	R303		2024	
ELEMENT	CORE PER CENT	CLADDING* PER CENT	CORE PER CENT	CLADDING* PER CENT
Copper	0.8 to 1.2	0.1	4.0 to 4.5	0.1
Magnesium	2.0 to 3.0	0.1	1.0 to 1.5	Not reported
Silicon	0.15 to 0.25		0.2 to 0.3	
		(Fe + Si)0.7		(Fe + Si)0.7
Iron	0.3 to 0.4		0.3 to 0.5	
Zinc	5.0 to 7.0	1.8 to 2.7	0.005	0.1
Chromium	0.1 to 0.2	0.3	0.05	Not reported
Manganese	0.05	0.05	0.5 to 0.7	0.05
Titanium	0.05	Not reported	0.3	Not reported
Nickel	0.06	0.05	0.05	Not reported
Other elements:				
Total	Not taken	0.15	Not taken	Not reported
Each	Not taken	0.05	Not taken	Not reported
Aluminum	Remainder	Remainder	Remainder	99.3 min.

*Manufacturer's data.

The 2024 alloy draw pieces were heated at 775 F for two hours, furnace-cooled at the rate of 50 F per hour to 400 F and air-cooled.

LUBRICANTS

The two most widely used lubricants were a sulfurized fatty oil (SFO) blend and a soap solution. The sulfurized fatty oil blend consisted of 10 per cent sulfurized fatty oil, 10 per cent lard oil and 80 per cent mineral oil (300 SSU at 100 F).

The soap solution was prepared by adding 8 grams of a high-titer (40-42 C) soda tallow soap to 100 ml of water. The mixture was heated to 180 F, at which temperature the soap is completely soluble. Test pieces intended for soap coating were immersed in this hot solution for about five minutes, then removed and permitted to dry at room temperature. When the soap solution was to be used as a liquid lubricant, the solution was heated only sufficiently to prevent jelling.

The sulfurized fatty oil lubricant was applied sparingly to the die and punch just before drawing. The draw piece was immersed in the lubricant for five to 10 seconds, placed in the testing machine and drawn.

Any aluminum pickup on the punch or die was removed by treatment in a 10 per cent sodium hydroxide solution maintained at about 200 F. The immersion time required for complete removal ranged from one to 15 minutes, depending upon the amount of pickup. An example of aluminum pickup on the die and punch is shown in Figure 3.

SURFACE TREATMENTS

Several surface treatments were investigated. In general the procedure used was as follows:

Pickle. Draw pieces which were given a pickle prior to drawing were immersed in a five to 10 per cent acid solution at room temperature for three to five minutes. The acids used were sulfuric, hydrochloric, phosphoric, chromic, nitric, acetic, formic, and oxalic.

Alkali. The effect of treatment with various alkaline materials was investigated. They included dilute solutions of sodium hydroxide, borax, and silicates having various ratios of Na_2O to SiO_2.

Oxide. Two oxide surface treatments were investigated—namely, an electrochemical oxidation process (Code A), and a chemical immersion process (Code B) using sodium carbonate and potassium dichromate. Details of these oxidizing processes are given in Appendix I.

Phosphate. Two phosphate surface treatments were tried—namely, a chrome-phosphate coating process (Code C), and a zinc-phosphate coating process (Code D). Details of these two processes are given in Appendix II.

SURFACE EVALUATION

Several surface-measuring instruments were examined for evaluating the condition of the drawn surface. A profilometer type was chosen because of its suitability in scanning curved surfaces. The instrument consists of three essential parts: the tracer unit, the amplifier and the autographic recorder. The instrument employs a 60-degree angle stylus the mechanical fluctuations of which are converted into electrical fluctuations and amplified to actuate an autographic recorder. The record represents the average surface roughness—not the profile—of the surface being scanned. The surface condition is recorded in microinches, root mean square.

Setup for Surface Evaluation. A lathe was found expedient in performing the surface evaluation test. The lathe rotated the draw piece slowly and uniformly while the tracer unit scanned the surface. The bottom

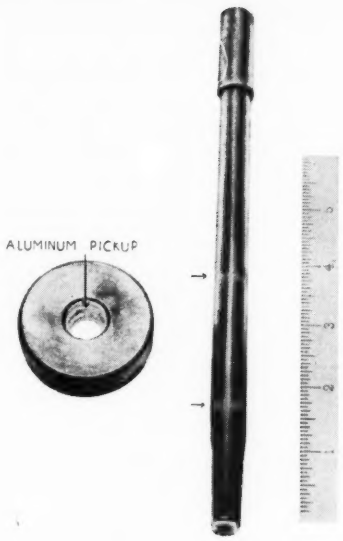

Figure 3. Example of excessive aluminum pickup occurring on die and punch.

of the draw piece was first cut off about ⅛ in. from its end and discarded. The remaining portion of the piece was then fitted to the end of a punch similar to the one used in the drawing operation. The other end of the punch was inserted in the chuck of the lathe for turning. The tail stock was brought up to the working end of the punch to true its rotation. The tracer unit was placed on the draw piece in such a manner that the stylus and skids rode on the crest of the rotating specimen. The fixture which held the tracer unit was attached to the automatic feed mechanism of the lathe. Thus by simultaneously rotating the chuck and operating the automatic feed mechanism, it was possible to scan, if desired, the entire surface of the draw piece as the stylus produced a spiral track on the surface of the specimen. Actually, however, only eight linear inches of the surface were scanned. This corresponded to five complete revolutions.

The rotating specimen had a surface speed of 20.7 in. per minute, the lowest speed permitted by the lathe. The automatic feed mechanism traveled at 0.73 of an in. per minute. This combination of motions produced a spiral having 19 turns per in. As the chart speed on the autographic recorder was 18 in. per minute, one revolution of the test specimen was equivalent to a distance of about one in. on the chart.

Interpretation of the Graph. The character of the graph depicted the roughness or smoothness of the surface. A relatively smooth surface was represented by a curve of small vertical amplitude in the lower portion of the graph. A large amplitude indicated that the surface roughness was not uniform.

Since most of the curves had a large amplitude, it seemed fitting to describe the graph by reporting the maximum and minimum microinch values as well as a value designated by a line drawn through the center of the densest portion of the graph. This line represents the average surface roughness, and, in the tables of this report, is designated as the "norm" value and it is shown in Figure 6.

RESULTS

PICKLED VERSUS NONPICKLED SURFACES

In exploratory work on the study of lubricants for the drawing of 2024 aluminum alloy, it was found that mild pickling before drawing was advantageous in reducing the draw forces. It was learned also that the degree of scoring is considerably reduced by the use of dried films, such as soap, in conjunction with liquid lubricants.

Table 2 compares the draw forces obtained with pickled and nonpickled draw pieces using respectively a dried-on film of soap, a sulfurized fatty oil blend, an eight per cent soap solution and a combined lubricant of a dried-on soap coat and the sulfurized fatty oil blend. The data clearly demonstrate that the five per cent sulfuric acid pickling treatment is beneficial in lowering the draw forces, although the improvement is slight.

The lowest draw forces were obtained when a dried-on soap coat was used in conjunction with the sulfurized fatty oil blend. The surface condition of the draw pieces was better with the combined lubricants than with those shown in Table 2.

OXIDE PRETREATMENT

Electrochemical Process (Code A). It was found that the drawing of aluminum could be greatly improved by pretreating the surface of the draw pieces with an electrochemically deposited oxide coating.

The electrochemical treatment used in the first experiment consisted of the treatment generally given to aluminum for corrosion protection; namely, a 30-

TABLE 2. EFFECT OF PICKLING (IN 5% H_2SO_4 FOR 5 MINUTES AT ROOM TEMPERATURE) ON LUBRICATION INDEX IN DRAWING R303 ALLOY

PRETREATMENT	LUBRICANT	LUBRICATION INDEX	CONDITION
Pickled	Soap coat from 8% soap solution	4450	Excessively scratched
Not pickled	Soap coat from 8% soap solution	4880	"
Pickled	SFO	5690	"
Not pickled	SFO	5800	"
Pickled	8% soap solution	4660	"
Not pickled	8% soap solution	4960	"
Pickled	Soap coat from 8% soap solution + SFO*	3440	Slightly scratched
Not pickled	Soap coat from 8% soap solution + SFO*	3890	"

*SFO = Sulfurized fatty oil

TABLE 3. EFFECT OF ELECTROCHEMICAL OXIDE TREATMENT (CODE A) TIME ON DRAWING R303 ALLOY, USING SFO (SULFURIZED FATTY OIL) AS LUBRICANT

ELECTROLYSIS TIME (MINUTES)	LUBRICATION INDEX	SURFACE ROUGHNESS (MICROINCHES, RMS)		
		Min.	Max.	Norm
60	4750	23	33	28
45	4890	23	40	32
30	4930	13	29	22
20	4880	19	25	22
10	4860	10	14	12
6	4720	10	14	12
2	4520	9	13	11
1	4260	6	10	8

TABLE 4. EFFECT OF ELECTROCHEMICAL OXIDE TREATMENT (CODE A) TIME ON DRAWING R303 ALLOY, USING MINERAL OIL OF 300 SSU AS LUBRICANT

ELECTROLYSIS TIME (MINUTES)	LUBRICATION INDEX	SURFACE ROUGHNESS (MICROINCHES, RMS)		
		Min.	Max.	Norm
60	6570	25	42	35
45	6100	26	44	35
30	5880	12	20	16
20	5880	8	18	13
10	6130	10	18	14
6	6080	5	8	7
2	5860	2	6	4
1	5660	3	8	5

minute treatment in a fifteen per cent to eighteen per cent sulfuric acid bath using a current density of about 12 amperes per square foot. The liquid lubricant used in drawing the electrochemically treated aluminum was a sulfurized fatty oil blend. The unusually smooth surface resulting from this preliminary test indicated that this pretreatment merited further investigation.

A study was made to determine the effect on drawing of varying the time of the electrochemical treatment from one to 60 minutes. The results are shown in Table 3. The lowest lubrication index (4260) was obtained with a treatment of one minute. It can be noted that the lubrication index increases with electrolysis time until 30 minutes is reached. Using the same time schedule of anodic treatment, similar tests were conducted with mineral oils of viscosity 300 and 600 SSU. These results are shown in Tables 4 and 5. The range in lubrication index for both of these liquid drawing lubricants is approximately the same. However, both are at a lubrication level of about 1000 units higher than the sulfurized fatty oil blend. The important factor is that the anodic pretreatment makes possible the drawing of aluminum with a mineral oil possessing no extreme pressure properties.

Since the data in Tables 3, 4 and 5 indicate that the 1-minute anodic treatment resulted in the lowest lubrication index, it would seem logical that the 1-minute treatment should be used for all future studies of the anodic pretreatment. However, pilot production studies which were being conducted simultaneously demonstrated that a 1-minute anodic treatment was inadequate to accomplish several successive drawing operations. It was soon learned that a 30-minute treatment was required. Consequently, laboratory studies that followed were made using a 30-minute anodic treatment.

Many exploratory tests were conducted to determine the most suitable lubricant for use in conjunction with the electrochemically treated surface. The first series of tests was to determine the effect of a sealing treatment. The results are shown in Table 6. It can be noted that the lowest draw forces were obtained with a stearic-acid treatment at 200 F for 10 minutes. No appreciable difference occurs between the use of a sulfurized fatty oil blend and a mineral oil

TABLE 5. EFFECT OF ELECTROCHEMICAL OXIDE TREATMENT (CODE A) TIME ON DRAWING R303 ALLOY, USING MINERAL OIL OF 600 SSU AS LUBRICANT

ELECTROLYSIS TIME (MINUTES)	LUBRICATION INDEX	SURFACE ROUGHNESS (MICROINCHES, RMS		
		Min.	Max.	Norm
60	6140	32	36	36
45	6430	32	40	35
30	5850	24	40	27
20	6040	15	23	20
10	5780	8	12	10
6	5660	6	14	10
2	5300	5	12	8
1	4900	4	10	7

TABLE 6. EFFECT OF SEALING TREATMENT ON DRAW FORCES, USING ELECTROCHEMICALLY PRETREATED (CODE A—30 MINUTE TREATMENT) R303 ALLOY

SEALING TREATMENT	LUBRICANT	LUBRICATION INDEX	SURFACE ROUGHNESS (MICROINCHES, RMS)		
			Min.	Max.	Norm
Stearic acid at 200F for 10 minutes	None	3200	24	36	27
Stearic acid at 200F for 10 minutes	SFO	3340	Not taken		
Stearic acid at 200F for 10 minutes	Mineral Oil	3320	24	36	27
Palmitic acid at 200F for 10 minutes	None	3560	19	29	26
Oleic acid at 200F for 10 minutes	None	4070	24	46	35
Water at 210F for 10 minutes	Mineral Oil	5670	17	30	24
2% soap solution at 190F for 10 minutes	SFO	3970	22	35	29
8% soap solution at 190F for 10 minutes	None	4750	Not taken		

of 300 SSU as a lubricant. Palmitic and oleic acid sealing treatments are effective media in reducing draw forces. Also, it was noted that a sealing treatment with a two per cent soap solution is superior to a water sealing treatment.

An attempt was made also to determine the effect of various lubricant additives on electrochemically pretreated (30 minutes) draw pieces. The results in Table 7 show that the addition of two per cent stearic acid or two per cent palmitic acid to mineral oil is beneficial in lowering the draw forces.

Bulk Oxidizing. In an attempt to overcome the difficulties that arose in individually handling the draw pieces for the electrochemical process, a method for bulk processing was tried. Results were satisfactory when about thirty draw pieces were placed in a small, woven, aluminum basket fitted with a tightly clamped aluminum lid, and were electrochemically processed. The lubrication indices of these draw pieces are shown in Table 8. Comparison is also made with draw pieces which were individually treated. The surface condition of both groups was satisfactory. A smooth and glassy surface was noted on all draw pieces.

However, when a large basket was made to hold approximately three hundred draw pieces, it was found that the pieces which were held in the center of the basket were not affected by the treatment; only the pieces in contact with the basket were satisfactorily processed. Many draw pieces lacked uniformity in the oxide coating.

TABLE 7. Effect of Additives in Drawing Lubricant Using Electrochemically Pretreated (Code A—30 Minute Treatment) R303 Alloy

Lubricant	Lubrication Index	Surface Roughness (microinches, rms) Min.	Max.	Norm
Mineral oil + ½% stearic acid	5220	Not taken		
Mineral oil + 2% stearic acid	4020	Not taken		
Mineral oil + 2% palmitic acid	3900	13	27	18
Mineral oil + 2% oleic acid	4620	10	18	14
Mineral oil + 5% oleic acid	4530	12	18	15
Mineral oil + 10% lard oil	4520	12	20	15
Mineral Oil + 10% lard oil and 1% oleic acid	4440	10	18	15
Lard oil + 10% oleic acid	5340	Not taken		
Lard oil neutralized with NaOH	5380	24	44	34
Lard oil + 10% oleic acid and 2% palmitic acid	4100	Not taken		

TABLE 8. Comparison of Lubrication Index Between Electrochemically Pretreated (Code A—30 Minute Treatment) Draw Piece (R303) Prepared Individually and in Bulk

Lubricant	Individual Lubrication Index	Bulk Lubrication Index
Stearic acid	3200	3800
10% oleic acid in lard oil	4230	4380
2% oleic acid in lard oil	4310	4580
10% diglycollaurate in mineral oil	4960	4890
SFO	4930	4700
½% stearic acid in mineral oil	5230	5220
10% oleic acid in mineral oil	5600	4310
10% glyceryl monoricinoleate	5840	5890

Despite the poor results obtained in these limited tests to pretreat the pieces in bulk, it is believed that a suitable method can be devised for the expeditious handling of draw pieces in production. A possible approach may be to use a conveyor system to carry the pieces through the entire process.

Chemical Immersion Process (Code B). This is a simple chemical immersion process for producing an oxide coating. It was used as a surface treatment in conjunction with other liquid or solid lubricants for the drawing of aluminum. Results are shown in Tables 9 and 10.

Although it was noted that the lowest draw forces were obtained with a 7 minute treatment, it was decided that the 30-minute treatment be used as the standard for testing drawing lubricants. This decision was based on the opinion that in production a thick coating would be needed to permit several successive drawing operations without requiring a retreatment. Therefore, all data were obtained employing a 30-minute pretreatment.

TABLE 9. Effect of Chemical Immersion Oxide Treatment (Code B) on Drawing R303 Alloy, Using SFO as Lubricant

Immersion Time (minutes)	Lubrication Index	Surface Roughness (microinches, rms) Min.	Max.	Norm
30	4170	15	30	23
20	4150	25	35	30
15	3880	Not taken		
10	3650	16	25	21
7	3310	Not taken		
5	3750	13	16	15
2	3660	12	17	14
1	3740	9	15	12

TABLE 10. EFFECT OF SEALING ON CHEMICAL IMMERSION PRETREATED (CODE B—30 MINUTE TREATMENT) DRAW PIECES (R303 ALLOY)

SEALING TREATMENT*	LUBRICANT	LUBRICATION INDEX	SURFACE ROUGHNESS (MICROINCHES, RMS) Min.	Max.	Norm
Palmitic acid	None	2640	20	38	28
Stearic acid	None	2880	26	39	31
Oleic acid	None	3140	32	46	34
Palmitic acid	SFO	2720	22	41	27
Stearic acid	SFO	2890	28	40	32
Stearic acid	Mineral oil	2890	27	45	33
Dichromate solution	SFO	4050	25	46	39
Water solution	SFO	4550	24	42	38
Dichromate solution	Mineral oil + 10% lard oil	3580	29	48	35
Dichromate solution	Mineral oil + 50% lard oil	3200	29	46	33
Dichromate solution	Mineral oil + 2% palmitic acid	3600	26	40	36
Dichromate solution	Mineral oil + 2% oleic acid	3850	24	43	33
Dichromate solution	Mineral oil + 2% lard oil neutralized with NaOH	4510	25	49	35
Dichromate solution	Mineral oil	5000	31	52	42

SFO = Sulfurized fatty oil.
*At 200F for 10 minutes.

Table 10 shows the effect of sealing of the oxide coating on the draw forces. It was noted that palmitic acid produced the lowest lubrication index of the sealing treatments with organic acids. The water sealing Treatments were not so effective as the organic acids. The dichromate seal, however, is more effective than the water sealing treatment.

PHOSPHATE PRETREATMENT

Two types of phosphate pretreatment, namely a chrome-phosphate coating (Code C), and a zinc-phosphate coating (Code D) were investigated. Results indicate that neither is satisfactory as a surface pretreatment for drawing aluminum. The data presented in Tables 11 and 12 show that pickling before phosphating the surface aids in lowering the draw forces, the explanation being that the oxide coating, normally found on all aluminum surfaces, is a barrier which prevents reactivity of the phosphating solution and is removed by the pickling process.

Various lubricants were tried in conjunction with pickled and phosphated draw pieces, but none was considered satisfactory because the surface condition of the draw pieces was rather poor. The drawn surfaces were marked with moderate to excessive scratches running the entire length of the draw pieces.

ALUMINUM ALLOYS R303 AND 2024

The aluminum drawing investigation that followed was conducted on clad 2024 aluminum alloy because clad R303 alloy was no longer available.

TABLE 11. EFFECT OF PICKLING (IN 10% H_2SO_4 AT ROOM TEMPERATURE FOR 5 MINUTES) AND CHROME PHOSPHATING (CODE C) ON LUBRICATION INDEX IN DRAWING R303 ALLOY, USING SFO AS A LUBRICANT

PRETREATMENT	FIRST MAX. FORCE	LUBRICATION INDEX	CONDITION
Pickled, phosphated, rinsed, and oven-dried	3100	5310	Moderately scratched
Pickled, phosphated, rinsed, and air-dried	3000	5100	,,
Pickled, phosphated, not rinsed, and oven-dried	3200	5610	,,
Pickled, phosphated, not rinsed, air-dried	3160	5530	,,
Not pickled, phosphated, rinsed, and oven-dried	4930	(a)	torn
Not pickled, phosphated, rinsed, and air-dried	4850	(a)	torn
Not pickled, phosphated, not rinsed, and oven-dried	4510	(a)	torn
Not pickled, phosphated, not rinsed, and air-dried	4340	(a)	torn

(a) Lubrication index was not obtained because the draw piece tore before the minimum and final maximum forces were reached.

TABLE 12. EFFECT OF PICKLING (IN 5% H_2SO_4 AT ROOM TEMPERATURE FOR 5 MINUTES) AND ZINC PHOSPHATING (CODE D) ON LUBRICATION INDEX IN DRAWING R303 ALLOY

PRETREATMENT	LUBRICANT	LUBRICATION INDEX	SURFACE CONDITION
Pickled, phosphated	SFO	5390	Moderately scratched
Not pickled, phosphated	SFO	6390	,,
Pickled, phosphated	Lard oil + oleic acid	4920	,,
Pickled, phosphated	Lard oil	5100	,,
Not pickled, phosphated	Lard oil	6090	,,
Pickled, phosphated	Mineral oil of 970 SSU	6080	,,
Not pickled, phosphated	Mineral oil of 970 SSU	7230	Excessively scratched
Pickled, phosphated	Mineral oil + 10% oleic acid	5630	Moderately scratched
Pickled, phosphated	Mineral oil + 1% oleic acid	7150	Excessively scratched

Comparative tests were conducted to establish the relative lubrication indices for both alloys when using various lubricating systems and the results are given in Table 13. It can be noted that the lubrication indices in all cases are higher for the 2024 alloy than for the R303 alloy. Slight differences in indices exist between the R303 and 2024 alloys when the oxide pretreatments are used. Much larger differences in indices were obtained when the draw pieces were pickled, soap coated, and drawn with SFO. These differences in lubrication indices account for the difficulty which has been experienced in the experimental manufacture of pilot production lots of 2024 aluminum alloy cartridge cases.

MISCELLANEOUS PRETREATMENTS

Silicates. Several exploratory tests were conducted to determine the effect of silicates of soda as a pretreatment for the drawing of 2024 alloy aluminum. The data presented in Table 14 indicate that the types of silicates included in this investigation are not an aid to the lubrication of aluminum. In general, the forces obtained in drawing aluminum pretreated with silicates of soda and using the SFO blend as the drawing lubricant are somewhat higher than those obtained when soap coating and SFO were used. In addition, the drawn-surface condition was considerably inferior. Numerous scratch marks appeared frequently, and several test pieces were torn during the drawing operation. The die and punch had to be removed often to remove the aluminum pickup. The lowest draw forces were obtained when the Na_2O to SiO_2 ratio was 1:2.00, using a 20 per cent solution.

Mineral and Organic Acids. Conditioning of the surface by pickling in dilute solutions of mineral and organic acids prior to drawing with an SFO blend results in various degrees of scratched draw pieces and a lubrication index greater than 4600. There was one exception. Pickling in acetic acid resulted in a lubrication index of 3830. The surface, however, was scratched. When the pickled surface was immediately coated with stearic acid and drawn with SFO, a vast improvement was noted in both a lowering of the lubrication index and a minimizing of the degree of scratching. Table 15 contains the data obtained from this investigation.

TABLE 13. COMPARISON OF LUBRICATION INDEX BETWEEN R303 AND 2024 ALUMINUM ALLOY

PRETREATMENT	LUBRICANT	LUBRICATION INDEX R303	LUBRICATION INDEX 2024
Pickled* and 8% soap solution coated	SFO	3440	4330
Electrochemical oxidation**	SFO	4930	4980
Electrochemical oxidation and stearic acid coated	None	3200	3310
Electrochemical oxidation and dichromate sealed	SFO	4670	4850
Chemical immersion oxidation†	SFO	4170	4890
Chemical immersion oxidation and stearic acid coated	None	2880	3460
Chemical immersion oxidation and dichromate sealed	SFO	4050	4840

*In 10% H_2SO_4 at room temperature for 5 minutes.
**Code A—30 minute treatment.
†Code B—30 minute treatment.

TABLE 14. EFFECT OF PRETREATMENT WITH SILICATES OF SODA ON 2024 ALLOY, USING SFO AS LUBRICANT

RATIO OF Na_2O TO SiO_2	SOLUTION STRENGTH, TEMPERATURE, AND DURATION OF PRETREATMENT	LUBRICATION INDEX	SURFACE CONDITION
1:1.60	10%, 150 F 2 min.	4270	Excessively scratched
	20%, 150 F 2 min.	4650	,,
1:2.00	10%, 150 F 2 min.	4130	,,
	20%, 150 F 2 min.	4080	,,
1:3.22	3%, 150 F 2 min.	4350	,,
1:3.75	10%, 150 F 2 min.	5270	,,
	20%, 150 F 2 min.	5720	,,

TABLE 15. EFFECT OF STEARIC ACID COATING ON ORGANIC ACID AND MINERAL ACID PRETREATED 2024 ALLOY, USING SFO AS LUBRICANT

PRETREATMENT	LUBRICATION INDEX	SURFACE ROUGHNESS (MICROINCHES, RMS) Min.	Max.	Norm
5% oxalic acid	4630	18	88	58
5% oxalic acid and stearic acid coated at 200 F for 10 minutes	3640	12	18	16
5% formic acid	4690	22	77	43
5% formic acid and stearic acid coated at 200 F for 10 minutes	3770	12	16	14
5% acetic acid	3830	18	38	24
5% acetic acid and stearic acid coated at 200 F for 10 minutes	3300	10	16	13
5% phosphoric acid	4750	28	>100	65
5% phosphoric acid and stearic acid coated	3750	10	19	16
5% nitric acid	5400	33	69	48
5% nitric acid and stearic acid coated	3930	19	46	28
5% sulfuric acid	5690	Not taken		
5% sulfuric acid and stearic acid coated	3960	12	22	16
5% hydrochloric acid	5050	>100	>100	>100
5% hydrochloric acid and stearic acid coated	3920	Not taken		

Inorganic Salts. The investigation also included treatment with inorganic salts. Results are shown in Table 16. In general, draw forces were high and the surface condition of the drawn pieces was poor. Several pieces tore during the drawing operation. A 10 per cent ammonium sulfate solution was best, with a lubrication index of 3590 when drawn with SFO. However, the surface condition was poor. Several scratch marks appeared on the drawn pieces. Pretreatment with 30 per cent hydrogen peroxide was unsatisfactory. The treatment of aluminum in a solution of 10 per cent zinc oxide and 0.5 per cent sodium hydroxide results in the deposition of zinc on aluminum. It was found that by treating the zinc coated aluminum draw pieces in a soap solution, the zinc is converted to a zinc soap, which appears to be an aid in lubrication. The draw forces are lower than most other inorganic salt treated pieces within the group.

SURFACE EVALUATION

Surface roughness data are presented in the tables, together with the lubrication index given for each lubrication study. Analysis of the data in Table 3 indicates that the smoothest surfaces were obtained with the pieces which were given the shortest pretreatment. In general, it was noted that the surface roughness increases as the pretreatment time is increased. A comparison of the surface data given in Tables 3, 4 and 5 shows that the surface condition is not appreciably affected by the type of liquid lubricant that is used. With reference to the values given in Table 6 and 7, it can be seen that the minimum, maximum, and norm values are at about the same level as those described in Tables 3, 4 and 5. There appears to be a slight correlation between the surface values and the lubrication index. However, it is noted that about 75 per cent of the microinch values fall within 15 to 30.

Table 9 shows the roughness values obtained in the time study of the draw pieces treated by the chemical immersion process (Code B). These data again show that the smoothest surfaces were obtained with the draw pieces which were given the shortest pretreatment, and that the surface condition varies with the extent of the treatment. In general, the longer the pretreatment, the greater the roughness. From an examination of the data presented in Table 10, it is apparent that the dichromate sealing treatment tends to increase the surface roughness. The majority of the values fall within the range of 30 to 38 microinches. Although this range is higher than the range of the electrochemically treated draw pieces, the differences are small. There also exists some overlapping in the values. Therefore the surfaces produced from either oxide pretreatment are considered equal.

When the surface is scored, such as was obtained in the draw pieces described in Table 14, it is impractical to obtain roughness readings because the roughness exceeds the capacity of the instrument. Therefore, surfaces whose microinch values are greater than 100 are not reported. The roughness readings reported in Table 15 shows the effect of stearic acid coating on acid pretreated draw pieces. The stearic acid coating produces a smoother surface, for it will be noted that a sharp reduction in microinch values was obtained for the stearic acid coated piece. The same pattern is observed in the lubrication index; namely, stearic acid coating resulted in a 10 to 40 per cent reduction in lubrication index. In general, this illustrates that a low lubrication index usually is accompanied by a low microinch value.

TABLE 16. EFFECT OF PRETREATMENT WITH INORGANIC SALTS FOR FIVE MINUTES AT 75F TO 85F ON 2024 ALLOY USING SULFURIZED FATTY OIL AS LUBRICANT

PRETREATMENT	LUBRICATION INDEX	SURFACE ROUGHNESS (MICROINCHES, RMS) Min.	Max.	Norm
30% hydrogen peroxide	4790	>100	>100	>100
10% zinc oxide + 0.5% NaOH + dried on soap coat from 8% soap solution	3950	29	42	36
10% ammonium sulfate solution	5470	>100	>100	>100
10% potassium aluminum sulfate	5310	>100	>100	>100
10% waterglass + 5% borax	5150	>100	>100	>100
5% sodium metasilicate	5490	>100 and tearing	>100	>100
1% TSP* + 2% sodium metasilicate	6000	>100	>100	>100
1% TSP + 4% sodium metasilicate	5280	>100	>100	>100

*Trisodium phosphate

DISCUSSION

ELECTROCHEMICAL PRETREATMENT

General. The spectacular results obtained with electrochemically treated (Code A) draw pieces clearly demonstrate that conditioning the aluminum surface prior to drawing is of primary importance. The electrochemical process produces a surface coating which is an integral part of the parent metal. It is porous, and therefore serves as a host for the liquid lubricant. It is ductile, and can withstand the severe pressures and elongations existing during a drawing operation. The value of this coating is further demonstrated by the severe drawing that can be accomplished with only mineral oil, a nonpolar lubricant. Thus, the electrochemical pretreatment provides an ideal surface for drawing aluminum.

It would seem that the improved lubrication afforded by the electrochemical pretreatment would be reflected in a lower lubrication index value. Instead it was found that the lubrication index was somewhat higher than the index of an untreated aluminum draw piece, each being drawn with the same liquid lubri-

cant. A possible explanation for this apparent anomaly is as follows: The lubrication index is a measure of the total energy required to draw an aluminum draw piece. In the case of the untreated aluminum draw piece, the total energy expended is equal to the sum of the work required to plastically deform the aluminum and to overcome the forces of friction between the work and the tools. However, in the case of the electrochemically pretreated draw piece, there is the added work necessary to deform the oxide coating, which has an appreciable thickness and hardness. Consequently, the level of lubrication index is correspondingly higher. It follows, therefore, that lubrication indices are comparable only when differences in lubricating systems of the same general type are being investigated.

Many investigators have reported on the structure of aluminum surfaces which are produced electrochemically. Edwards and Keller (4) report their findings in an article which is generously illustrated with photomicrographs obtained by means of the optical and electron microscopes. The photomicrographs reveal that the coatings have a "cellular structure composed of walls of oxide surrounding the pores or, what is more likely, a group of pores." Also, the oxide coating appears to "consist of two layers—an upper layer, dark and without visible structure, and a lower layer next to the metal, which shows alternate light and dark bands more or less radically disposed toward the centers from which growth started. Closer examination reveals further details, such as small oval or circular markings in the area near the upper zone and in other areas. Near the oxide-metal interface, a darker band is evident. Just beneath this band, there appears a delicate tracery which reveals the contour of the advancing oxide front. This is the location of the barrier layer where the significant growth processes are taking place."

Further evidence that the anodic coating is porous is given by Edwards (5), who states that "The oxide itself is a nonconductor and there must be innumerable capillary pores or channels which penetrate the coating and carry the electrolyte" to the base aluminum where the oxidation process occurs.

Thickness of Electrochemical Coating. It is known that aluminum exposed to the atmosphere always bears on its surface a natural film of oxide. Investigators (6) report the thickness of the film to be of the order of 0.5×10^{-6} inch. Films of greater thickness are readily produced on aluminum by special anodic treatment processes. The thickness will depend upon the type of electrolyte used, the voltage, and the time employed in the process. It is reported (6) that, in general, commercial anodic coatings have a thickness varying from 0.0001 to 0.0096 inch. However, in a sulfuric acid bath, a coating of 0.0004 inch thickness (7) is formed by a half hour anodic oxidation at a current density of 12 amperes per square foot.

Abrasion resistance data (8) on anodically produced coatings on aluminum are reported by Arlt. He states that "when abrasion values are related to oxidizing time, it appears that the abrasion resistance approaches a maximum for the processing conditions employed. There are some indications that the unsealed coatings drop off in abrasion resistance after a critical oxidizing time has been reached. This is also reflected in the thickness values." The same trend was observed in this investigation. From the data presented in Table 3, it will be noted that the highest draw forces, as indicated by the lubrication index, were obtained with the 30 minute pretreatment. It is of interest to note that Arlt's data show that the maximum abrasion resistance is obtained from coatings produced by a 40 minute treatment. Both data cover the range from 1 to 60 minutes, and the peak in the curve exists at approximately the 30 to 40 minute treatment. Although coatings produced electrochemically are quite hard, and referred to as being comparable in hardness with their mineral counterpart corundum, Hill and Mason (9) report that "these coatings are surprisingly elastic in spite of their mineral like hardness." It may be this "elastic" characteristic of the anodic coating that makes possible the drawing of aluminum. The explanation seems to be that as the bare metal stretches during the drawing operation, the coating elongates to supply the necessary coverage and protection.

Microscopic Examination of Coating. An attempt was made to understand the mechanism by which the anodic pretreatment aids in the drawing of aluminum. The coatings produced on aluminum R303 and 2024 were examined with a microscope and the examination showed that the surface of aluminum anodized in sulfuric acid for 30 minutes at a current density of 12 amperes per square foot was not smooth. The surface has a crazed appearance being covered with a labyrinth of minute fissures running in many directions. Keller and Wilcox (10) report that "the electrolyte used for the anodic treatment causes a slight etching attack on the constituents and matrix." The oxide first formed as the coating growth progresses is in contact with the electrolyte, and is subject to its solvent action throughout the process. The structure of the oxide coating will depend upon the alloying elements in the exposed surface of the draw piece. These elements may be in solid solution, they may form intermetallic compounds which can be put into solid solution by thermal treatment, or they may be intermetallic compounds which are insoluble in solid aluminum. These compounds, or microconstituents, are attacked differently by the electrolyte; some are dissolved or oxidized either at the same rate or more rapidly than the aluminum matrix. The products of these transformations constitute the anodic coating.

The only explanation arrived at from these studies is that the spongy coating produced by the

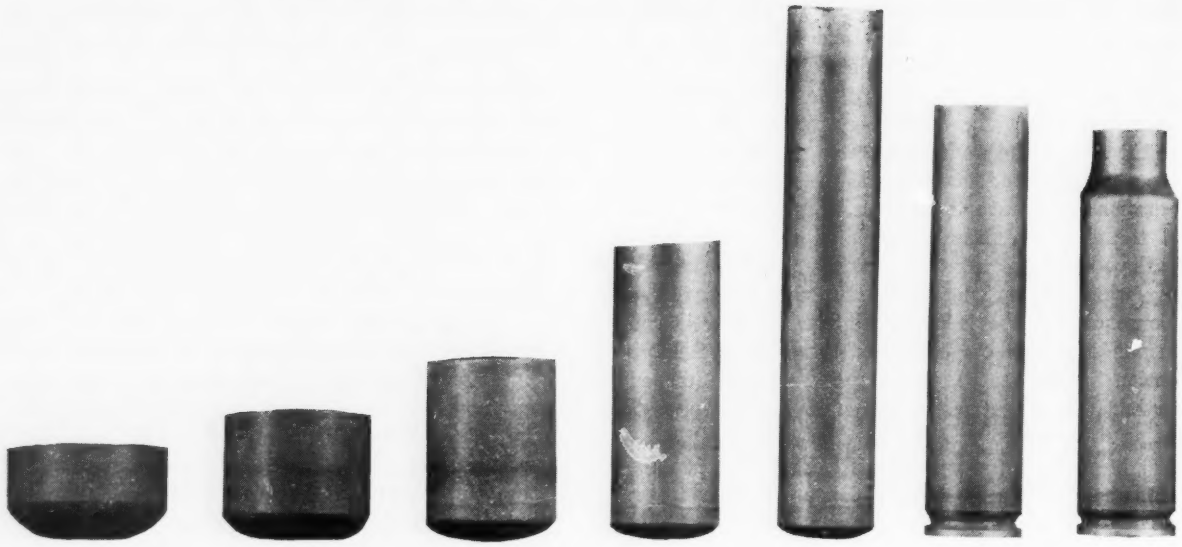

Figure 4. Drawing sequence of Cal. 0.30 Aluminum Cartridge Case.

electrochemical treatment serves to harbor the liquid lubricant. The tenacious and ductile properties of the coating also are important in providing the barrier between aluminum (the work) and steel (the tools).

ELECTROCHEMICAL PRETREATMENT IN PILOT PRODUCTION

Drawing. The principal benefit derived from the use of an anodic pretreatment for aluminum drawing is the number of successive drawing operations that can be accomplished from one pretreatment. For example, in the manufacture of caliber 0.30 and 0.60 cartridge cases, using a four-draw schedule, it was found that the electrochemical pretreatment given the cup was sufficient to process the lot through the four drawing operations. The liquid lubricant employed during the drawing operation consisted of a sulfurized fatty oil blend. The sequence of operations consisted of the following: The pretreated cup was given the first draw, using SFO blend. The liquid lubricant was removed by means of a trichloroethylene vapor degreaser. The cleaned draw pieces were given an annealing treatment, and on cooling were ready for the second drawing operation, which was accomplished simply with the aid of the SFO blend. This cycle was repeated until the final drawing operation was accomplished. The appearance of the surface at each of the drawing operations is shown in Figure 4 for the caliber 0.30 cartridge case.

From the preceding discussion of the sequence of operations, it will be noted that the anodized surface is not adversely affected by the annealing treatment. This is an important factor, and simplifies the drawing procedure considerably. Other investigators have found that anodizing aluminum prior to heat treating is beneficial. Gresham and Hall (11) report that an anodic coating on aluminum will prevent minute superficial cracking of the surface during the high temperature annealing treatment.

The anodizing pretreatment also has been used successfully for both the clad and bare 7075 alloy aluminum during caliber 0.30 and 0.60 pilot-lot production tests.

It is of interest to note also that the electrochemical pretreatment has been employed successfully in the drawing of the Aircraft Personnel Catapult Cartridge Case, using 5052 alloy aluminum. This is a reverse drawing operation (12,13) without reduction of metal thickness along the side wall. After several trial experiments it was found that a 2 minute electrochemical treatment prior to drawing was the most suitable pretreatment for this operation. The 30 minute pretreatment resulted in wrinkled metal along the side wall and in numerous rub marks. Therefore it was unsatisfactory. Several thousand of these cartridge cases have been manufactured with the electrochemical pretreatment. The use of this pretreatment has eliminated many shop difficulties, such as galling, scratching, metal pickup on tools and tearing.

Forging. The electrochemical pretreatment has been successfully employed in hot forging the head of Cartridge T109 for Catapult, Aircraft Personnel, T5, using 2017 alloy aluminum. The difficulty encountered in this forging operation was that of frequent aluminum pickup on the tools, which resulted in poor sur-

Figure 5. Head of cartridge T109 for catapult aircraft personnel T5. Left: head forged at 750F using graphite as a lubricant; Center: machined blank prior to forging; Right: head forged at 400 F previously electrochemically treated and lubricated with stearic acid.

faces and the need for frequent die cleaning. Figure 5 illustrates the difference in results obtained with a machined blank forged at 400 F using graphite as a lubricant, and the same component forged after being given an electrochemical pretreatment. A pilot production lot of three hundred units was hot forged in this manner without any difficulty.

Extruding. Tests were conducted to determine the suitability of an electrochemical pretreatment on bare 7075 alloy aluminum employing a backward extrusion process. A 1/2 in. diameter and 9/16 in. high slug was extruded to an overall height of 1-3/4 in. Caliber 0.30 cartridge cases were made from the extruded pieces.

Excellent results were obtained by giving the slugs a 30 minute pretreatment, and coating them with stearic acid.

CHEMICAL IMMERSION PRETREATMENT

The literature reports (14) that the oxide coating produced by the chemical immersion process is usually

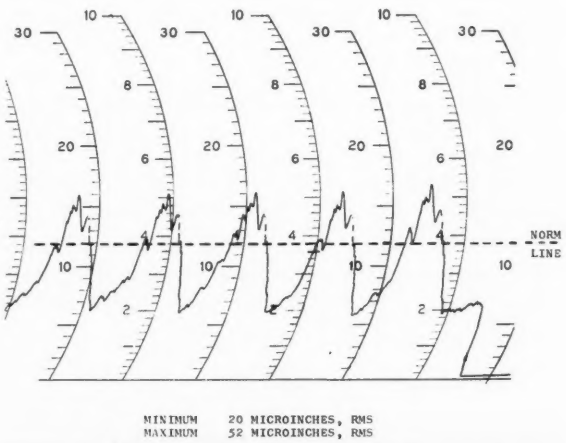

Figure 6. Surface roughness record of an electrochemically treated draw piece using the 0 to 100 scale (O to 10 scale × 10).

less resistant to abrasion and corrosion than the electrochemical coating. Nevertheless, tests have shown that this oxide coating (Code B) serves adequately in the drawing of aluminum.

Only a limited study was made of the oxide coating produced by the chemical immersion process. Microscopic examinations of the coating (X 100) do not reveal sufficient information to explain the mechanism which makes possible the drawing of aluminum. This oxide surface appears to be mildly etched. It does not exhibit deep etch marks, such as were noted in the surface of the electrochemically treated aluminum.

The principal advantage in the use of this oxide pretreatment is its simple procedure of application. No special equipment nor individual handling is required. This is an important factor when large production quantities are to be processed. In addition, the chemical immersion process is less costly than the electrochemical process from the standpoint of the special equipment and the electrical power that are required.

CHEMICAL IMMERSION PRETREATMENT IN PILOT PRODUCTION

The chemical immersion pretreatment plus the dichromate sealing treatment will successfully permit the processing of caliber 0.30 aluminum cartridge cases through two consecutive drawing operations. Three consecutive drawing operations have been accomplished with partial success. The sequence of drawing operations is the same as the one described for the electrochemically treated draw pieces. The liquid drawing lubricant is the sulfurized fatty oil blend. The alloys used in the production trial tests were bare 7075, and clad 7075 and R393.

The chemical immersion pretreatment was tried in the fabrication of caliber 0.60 cartridge cases, using clad 7075 alloy. The first drawing operation was successful. The draw pieces could not be processed through the second drawing operation without another surface pretreatment. However, in order to avoid delay in the processing of this lot, it was deemed advisable to pretreat electrochemically the draw pieces for the remaining draws.

PHOSPHATE PRETREATMENT

The two types of phosphate pretreatments used were intended primarily to apply a nonmetallic coating which would serve as a host to the liquid lubricant. One process produced a chrome phosphate coating (Code C). The principal constituents in its formulation are chromates, phosphates, and fluorides (15). The other process produced a zinc phosphate coating (Code D). Both pretreatments produced a thin, dense coating which was well integrated with the parent metal.

The phosphate pretreatments were not found to be advantageous in drawing aluminum. The lubrication indices obtained with both pretreatments were high, and generally of the same order of magnitude.

In addition, the drawn surface conditions were considered poor.

MISCELLANEOUS PRETREATMENTS

The use of silicate as an aid in the hot working or shaping of metals was reported as early as 1948 by Carpmaels and Ransford (16) who found that a solution of silicate of soda with dilute hydrochloric acid can be used successfully as a lubricant in the forming of metals.

However, the data on the use of silicates in this study show that silicates do not lend themselves to the successful lubrication of aluminum. Similarly, the various mineral and organic acid pretreatments which were tried did not prove to be adequate as drawing aids.

The most promising inorganic pretreatment was the zinc oxide plus sodium hydroxide. Logozzo and Neill (17) report that aluminum can be zinc plated by immersion in a 10 percent zinc oxide and 0.5 percent sodium hydroxide solution maintained at 60 F to 80 F. Since aluminum is less noble than most of the common metals, it will replace these metals from solutions of their salts. The alkaline sodium zincate solution dissolves the thin oxide film from the aluminum surface, and replaces it with a thin layer of metallic zinc. When the aluminum surface is completely covered with metallic zinc, the reaction virtually ceases. Most of the reaction appears to take place during the first few seconds of the immersion period, which is from 30 seconds to two minutes in duration. The results obtained from these tests indicate that the deposit of metallic zinc on aluminum serves adequately in anchoring the lubricant to the surface.

SURFACE EVALUATION

The surface condition of a draw piece is one of the important factors in determining the merits of a lubricant. A poor lubricant will produce a rough surface, i.e., the surface will be scored, indicating that metal seizure occurred during the drawing operation. Conversely, a smooth surface, or one which is free from score marks, will indicate good lubrication.

It was found that correlation exists between surface values and lubrication indices. This will best be seen in microinch values reported for the study of electrochemical pretreatment (Tables 3, 4 and 5). In general, surface studies served a useful purpose, particularly for gross differences. However, because of the overlapping of values in many instances, greater reliance was placed on the lubrication index for the evaluation of lubricants.

CONCLUSIONS

Laboratory tests have demonstrated that the condition of the aluminum surface is equally as important as the drawing lubricant. An oxide coating produced either by electrodeposition process or by a chemical immersion process is advantageous in forming aluminum. A sulfurized fatty oil blend is an excellent liquid drawing lubricant for use in combination with either of the oxide surface pretreatments.

Other surface pretreatments were inferior to the oxide pretreatments.

The lubrication index with clad aluminum alloy R303 is lower than with clad alloy 2024 when drawn under similar conditions of pretreatment and liquid drawing lubricant.

Shop tests have corroborated laboratory finds in the drawing of both clad and bare 7075, R303, 2024, and 5052 aluminum alloys. Several consecutive drawing operations were accomplished successfully with only one oxide pretreatment.

Limited shop tests have shown that forging and extrusion of aluminum are facilitated by the oxide pretreatment.

ACKNOWLEDGMENT

The author acknowledges the assistance of Mr. Souren Sadjian in conducting most of these tests and wishes to thank Mr. James W. Mitchell, Dr. Henry Gisser, Mr. E. R. Rechel and Mr. C. C. Fawcett for their interest and encouragement in this work.

APPENDIX I

OXIDE TREATMENT

CODE A.

1. Alkaline clean at 180 F for 2 minutes:
   3 oz/gal sodium metasilicate.
   0.3 oz/gal alkyl aryl sulfonate.
2. Water rinse (cold)
3. Electrolytic treatment:
   (a) Electrolyte: sulfuric acid, 15% to 18% by volume.
   (b) Temperature of bath: 70 to 77 F.
   (c) Current density: 12 to 13 amperes per sq ft.
   (d) Time: 30 minutes
4. Water rinse and dry.

Two sealing treatments were used, as follows:

1. Hot water sealing at 200 to 210 F for 15 minutes.
2. Dichromate sealing using 44 lb of sodium dichromate per 100 gallons of water at 180 to 190 F for 10 minutes.

CODE B.

1. Alkaline clean at 160 to 180 F for 2 minutes:
   3 oz/gal sodium metasilicate
   0.3 oz/gal alkyl aryl sulfonate.
2. Water rinse (cold).
3. Pickle in concentrated sulfuric acid at room temperature for 1 minute.
4. Water rinse (cold).
5. Pickle in 8% phosphoric (85%) acid plus 0.8% surface-active agent of the polyether-alcohol type at 110 to 120 F for 2 to 5 minutes.
6. Water rinse (hot).
7. Chemical treatment at 180 F for 30 minutes:
   23.3 lb sodium carbonate and 13.3 oz potassium dichromate per 100 gallons of water.
8. Rinse (cold or hot) and air-dry.
9. Seal at 180 F for 10 minutes in a solution of 44 lb of sodium dichromate per 100 gallons of water.
10. Water rinse (hot).
11. Dry with aid of forced hot air.

(See page 539 for Appendix II and Bibliography)

Chemical Nature of Extreme Pressure Lubrication

*by George Hugel**

ABSTRACT

Engine performance can be improved and seizing can be prevented by incorporating an organo-metallic complex in the lubricating oil. The complex is selected from materials which decompose at high temperatures and produce a solid mineral deposit.

It has been proved that the formation of this deposit and its subsequent elimination play an important part in the mechanism of lubrication. The elimination of the deposit is made easier by selecting the lubricant in which the complex is dissolved.

Each material chosen will contribute its own characteristic lubrication properties. Various materials may be combined to produce lubricants capable of improved performance.

INTRODUCTION

In a preceding paper[1] on the functioning of extreme-pressure additives, it was found that chemical reactions with lubricated surfaces are favored by pressure. It can be shown that good extreme-pressure additives are not removed by heavy pressures; on the contrary, they are strongly absorbed on the rubbing surfaces, and their decomposition is hastened by the temperature rise caused by friction. In the extreme case in which the test rig is stopped by imposing too great a pressure, the stopping cannot be attributed to failure of lubricant. Since the lubricant film is broken or destroyed, it is not present and cannot be held to blame for what happens in its absence. Further, the products of the reaction with the rubbing surfaces under these conditions are no longer lubricants and should not be so considered. The conclusion was reached that chemical attack of the rubbing surfaces and the formation of iron sulfide or chloride, which are less firmly incorporated in the metallic surfaces than are the iron atoms from which they are derived, produce surfaces that can be removed by rubbing. It is to this removing of the reaction products that the main action in extreme-pressure lubrication can be attributed.

CHEMICAL ACTION

It is easy to conceive that the chemical reaction is most intense on projecting points of the rubbing surfaces, for it is on these points that pressure is the heaviest. Chemical reaction smooths surfaces, not only by removing asperities, but also by filling up the holes with iron sulfide or chloride reaction products. One can also imagine that these reaction products, which are shed as soon as formed, function as an array of solid particles between the two rubbing surfaces, somewhat in the fashion of very small ball or needle bearings.

The chemical action of the E-P additives permits the continual renewing of the compressed and pressure-hardened surfaces. These additives permit, or even encourage, wear of the lubricated surface; however, such wear is much less than that which would take place without the additive. The tearing up of large particles in the absence of E-P additives is replaced by an orderly and far less destructive and limited chemical attack of the surfaces.

The relative importance of the chemical attack per se, and of the solids which are formed by the chemical attack, remain to be established. One action of the reaction products is limited to forming a protective screen between the two metal surfaces which prevents seizing. The solid iron sulfide or chloride could also play the part of an abrasive, able to abrade and polish the rubbing surfaces. Such action would be related to the hardness of the reaction product and to the quantity formed.

The chemical action is more complex. The formation of the solid wears the metal surfaces and causes polishing, as described. However, it is by no means settled that the reaction product need be formed solely from the metal of the sliding surfaces. It may not be necessary to destroy the bearing surfaces to form beneficial reaction products. The possibility exists that all the components to form the solid reaction products can come from additives in the lubricant. To explore this possibility, a search was made for oil-soluble complexes which:

a) Contain aliphatic groups with long chains to confer solubility;

* Professor, Institute Francais du Petrole, 4 Place Bir-Hacheim, Rueil-Malmaison (Seine-ξ -Oise), France.

[1] Hugel, G., "Fragen der Schmierölforschung," Erdöl und Kohle, v. 8, n. 9, September 1955, pp. 651-655.

TABLE 1 Effect of Molybdenum Laurylxanthate on Load Carrying Capacity in the Faville Test

	A		A + 2% B		A + 4% B		A + 6% B	
MOTOR VOLTS	LOAD KG	TORQUE	LOAD KG	TORQUE	LOAD KG	TORQUE	LOAD KG	TORQUE
80	375	0.02	350	0.02	375	0.02	325	—
100	625	0.14	700	0.13	750	0.14	600	0.10
120	625	0.30	1125	0.23	1325	0.25	1075	0.22
140	—	—	1700	0.40	1950	0.42	1800	0.35
160	—	—	—	—			>2000	0.37

A = Mineral Oil (SAE 30), B = Laurylxanthate of Molybdenum

b) Contain a metal and sulfur (or oxygen); and
c) Decompose at temperatures reached under extreme-pressure conditions, that is to say between 200 and 300°C, to deposit a mineral compound insoluble in lubricating oils.

Such a complex must as far as possible be chemically inert, and must not attack the surfaces to be lubricated. Apart from being able to tailor the properties of stability to obtain the desired result, this approach also permits selecting and controlling the properties of the solid formed within the oil film. Hardness especially can be controlled by a well-advised choice of a metal or a metal compound. For example, one should be able to produce solid decomposition products as widely different as metallic copper or mercury, metal oxides of lead or aluminum, or sulfides of nickel or molybdenum.

TESTS AND RESULTS

Organo-molybdic compounds were chosen to be explored first. The very first were the molybdic xanthates. These, however, were not stable enough, since they decomposed at room temperature in a few days. Nevertheless, the experiments were useful, for they gave some interesting results and showed that the basic idea was sound. As more stable molybdic complexes were sought, the molybdenum blues were tried. These are soluble in mineral oils in any proportion and are quite stable. Solutions withstood heating in air at 120°C for weeks without decomposition.

(*a*) *Faville Rig.* In order to test extreme-pressure lubricants, either the Faville or the Four-Ball Test Rigs were used. Emphasis was on the former and its test pin was examined with both the microscope and the profile meter. Tables 1 and 2 give results obtained with molybdic xanthates. The lauryl or the butylxanthate of molybdenum are respectively dissolved over a range of concentrations in mineral oil. One can see that optimum performance is reached between two and four per cent for the laurylxanthate, and at about two per cent for the butylxanthate. These results are interesting because, at the same concentration, the butylxanthate produces more of the solid reaction products than does the laurylxanthate. In order to have good lubrication, it is necessary to secure a minimal deposit. The quantity may be very small. Greater quantities do not change the performance appreciably.

A second point of interest to note is the difference between the two xanthates in the tests with six percent additive. With equal loads, for example 1800 kg, the torque is 0.35 for the laurylxanthate, compared with 0.56 for the butylxanthate. As the friction coefficient is proportional to the torque, other things being equal, it is to a difference of the friction coefficient that one must attribute this difference in torque. It is therefore concluded that aliphatic groups, attached to the molybdenum by means of the xanthogen group, play an appreciable part in friction effects.

The examination of the Faville test pins showed, on the places on which the pressure of the jaws was exerted, a brown-black color from molybdenum-oxy-sulfide. The surface was smooth and oily to the touch. Under the microscope, it was possible to see shoals of very fine white lines, perpendicular to the axis of rotation, separated by large dark bands. According to the angle of incidence of illumination, these lines may also appear black, separated by very brilliant bands.

The pins were examined with a profilometer to learn if these lines corresponded to scoring. Even at graphic enlargement of 10,000x in a perpendicular direction to the axis, no trace of scoring could be observed. In contrast to the parts of the pin not subjected to load, which showed a very uneven profile, the loaded areas showed a smooth surface with no trace of asperities or hollows. It is difficult to put a

TABLE 2 Effect of Molybdenum Butylxanthate on Load Carrying Capacity in the Faville Test

	A + 2% of butylxanthate of molybdenum		A + 6%	
MOTOR VOLTS	LOAD KG	TORQUE	LOAD KG	TORQUE
80	325	—	300	—
100	700	0.12	575	0.08
120	1175	0.24	1025	0.19
140	>2000	0.40	1400	0.34
160	—	—	1800	0.56

A = Mineral Oil (SAE 30)

proper interpretation on these lines since they should correspond to inequalities in the deposits covering the surface.

It was concluded that the action of a solid deposit on the lubricated moving surface makes it easier to polish the surface and that high performances result in part from this polishing action.

(*b*) *Four-Ball Rig.* The importance of the solid reaction product and of the time necessary for its formation may be demonstrated by tests with the Four-Ball Rig. Table 3 summarizes the results obtained according to: (a) the standard method in which one renews the four balls after each test, and (b) a "grinding test" in which the same balls are submitted to a series of increasing pressures. A solution of two percent of molybdenum blue, complexed by dicetylthiophosphate, was dissolved in a SAE 30 mineral oil for the tests in Table 3. The oil-soluble molybdenum blue does not attack iron. Tests on oil deterioriation in the presence of iron give complete assurance on this point. The sole factor in these experiments with the Four-Ball Rig is thus the formation of a solid reaction product produced at points of high pressure from a sulfur compound of molybdenum.

In the grinding tests, the solid reaction product has time enough to form while the pressure exerted on the balls is increasing. In the standard tests, on the other hand, time is limited and it is possible that the quantity of oil between the balls in contact area is not sufficient to form a deposit which is coherent and thick enough to resist the high pressure. Important differences were found in the two types of tests which are believed to be related to the formation of this solid deposit. The importance of this conclusion is obvious.

(*c*) *Effect of Solvent Carrier.* However, one must not neglect the contribution of the carrier which must carry the mineral complex to the pressure area. To produce evidence on this point, one may dissolve the same complex (the molybdenum blue complexed by didecyl thiophosphate) in other solvents, and compare the performances obtained in relation to the solvent used (Table 4). The solvents investigated were bright stock, tributylphosphate, hexamethylphosphoramide and chlorinated paraffin. They are different not only in their chemical constitution, but also in their physical properties.

TABLE 3 Effect of Molybdenum Laurylxanthate on Load Carrying Capacity in the Four Ball Test

A + 2% B			
STANDARD TEST		GRINDING TEST	
PRESSURE	SEIZING DELAY	PRESSURE	SEIZING DELAY
120 kg	60 sec.	120 kg	>60 sec.
160	60	150	>60
180	3	180	>60
190	Instantaneous	200	>60
		220	>60
		240	>60
		260	30

A = Mineral Oil (SAE 30), B = Molybdenum Laurylxanthate

TABLE 4 Faville Test Rig (2% of Molybdenum Blue in Various Solvents)

	A		A + 2% B		C		C + 2% B	
MOTOR VOLTS	LOAD KG	TORQUE	LOAD KG	TORQUE	LOAD KG	TORQUE	LOAD KG	TORQUE
80	325	—	275	—	325	—	425	0.02
100	525	0.12	600	0.12	675	0.10	850	0.14
120	675	0.24	1075	0.24	1150	0.23	1300	0.24
140	700	0.44	1275	0.44	1625	0.42	1800	0.44
	D		D + 2% B		E		E + 2% B	
80	250	—	350	—	275	—	325	—
100	375	0.10	625	0.14	450	0.08	575	0.11
120	450	0.24	800	0.24	650	0.23	1075	0.23
140	575	0.40	925	0.40	1025	0.40	1475	0.40

A = Bright stock, B = Molybdenum blue, C = Tributylphosphate, D = Hexamethylphosphoramide, E = Clhorined paraffin

The results obtained with molybdenum blue in mineral oil appear to be somewhat independent of viscosity. It is therefore concluded that viscosity per se is not too critical.

The results obtained with various solvents depend primarily upon the performance of the solvent itself. If the plain solvents are classified in order of increasing performance, it is found that the same sequence with their solutions of molybdenum blue is obtained. It is also noted that the improvement varies greatly from one solvent to another. For 140 volts, a load improvement of 575 kg is obtained with bright stock, 175 kg with tributylphosphate, 350 kg with hexamethylphosphoramid, and 450 kg with chlorinated paraffin. The improvement is greatest with bright stock and least with tributylphosphate. The test pins of the Faville Rig also show striking differences in these tests. A pin which was revolved in bright stock in which molybdenum blue has been added is browned by a deposit while the one from the solution in tributylphosphate shows a metallic iron surface without any trace of deposit. The removal of the deposit by tributylphosphate is very rapid. This is a general rule for oxygenated solvents which are very detergent or which have a high solvent power. The case of chlorinated paraffin is special; it is also detergent, but the ferrous chloride resulting from the chemical attack of iron by the chlorinated paraffin gives rise to a whitish deposit which is probably an iron phosphate originating from the phosphate contained in molybdenum blue complex.

The solvent or carrier may therefore intervene in several ways. It may remove the deposit, more or less rapidly according to its detergent qualities, or it may chemically change the nature of the deposit. It also interposes its own lubricating qualities.

TABLE 5 FAVILLE RIG TEST (2% OF MOLYBDENUM BLUE COMPLEXED BY LAURYLDIETHYLAMIDOPHOSPHATE)

MOTOR VOLTS	A′		B′		75 A′ + 25 B′		50 A′ + 50 B′		25 A′ + 75 B′	
	LOAD KG	TORQUE	LOAD KG	TORQUE	LOAD KG	TORQUE	LOAD KG	TORQUE	LOAD KG	TORQUE
80	300	—	400	—	400	0.02	425	0.02	400	—
100	650	0.12	775	0.08	775	0.12	850	0.12	875	0.12
120	1000	0.2	1325	0.22	1250	0.24	1275	0.24	1400	0.26
140	1375	0.32	1630	0.34	1675	0.42	1775	0.44	>2000	0.38

A′ = SAE 30 + 2% of Blue, B′ = Tributylphosphate + 2% of Blue

From the above it appears that the results are a statistical average of the local performances due in part to the deposit and in part to the carrier, with a random distribution over the whole rubbing surface and over the duration of the test. The diversified surfaces shown by microscope and the leveling action disclosed by the profilometer, plus the difference in action of the solvent carriers, suggest a host of processes and factors with large local variations. Unfortunately, these factors are known only very incompletely in kind and degree.

However, it is of the greatest importance to attempt to itemize probable friction processes as completely as possible. A comparison of the performance of molybdenum blue in bright stock and in tributylphosphate suggests that the detergency of bright stock is too low for best performance while that of the phosphate is too high. It was therefore surmised that a blend of the two base stocks would be better than either alone. Table 5 shows that a two percent solution of molybdenum blue in a blend of one part mineral oil and three parts tributylphosphate gives higher performance than a solution in either solvent alone. It is evident that there is an optimum degree of detergency.

While this finding is gratifying, it had been expected that the maximum performance would have been situated rather toward mixtures that are richer in mineral oil since, on the basis of detergency, the addition of only a small percentage of tributylphosphate is sufficient to obtain Faville test pins free of deposits. There is thus a possibility that a factor other than detergency contributes to optimum performance. This factor is best described as the high lubricating property of mineral oil. If the test pin of the Faville Test Rig is run in plain mineral oil, it will stop at a load of 600-700 kg. Examination of the pin shows a very rough surface with relatively large pieces of metal pulled away at some points. This plucking out of metal is called seizing.

Seizure cannot be attributed neither to a lack of oiliness nor to viscosity nor to lubricating power since the addition of two percent molybdenum blue, which is too small a quantity to modify greatly any of these properties, raises the Faville seizure load to 1300-1400 kg. There is no sign of seizure, and it is obvious that the solid film would tolerate still higher pressure. Since it has already been shown that detergency is a factor, small additions of tributylphosphate were added. The Faville load could then be raised to 1600 kg. Further additions of tributylphosphate permitted raising the load to even 2000 kg while the test pin remained in perfect condition. Further additions of tributylphosphate did not greatly increase load capacity, possibly because the oiliness factor of the mineral oil becomes too much diluted.

The findings of this research on the effect of detergency can be exploited in two ways. In the first, blends of mineral oil and oxygenated compounds, such as phosphates, could be prepared to give optimum detergency. In the second, synthetic molecules could be built which would combine these optimum qualities. Such a molecule could be a phosphate made from long-chain alcohols. For practical reasons, preference is given to the first method.

SUMMARY

A new type of E-P agent has been discovered in which an organo-metallic complex is used to produce beneficial solid deposits on rubbing surfaces at points of high pressure and temperature. One such compound, molybdenum blue, which meets other important requirements of solubility, stability and non-corrosiveness, has been found to be most effective in increasing the lubrication performance of several viscous fluids in both the Faville and the Four-Ball Test Rigs. Detergency has been found to be an important factor in this new type of lubricant and small additions of tributylphosphate greatly improve the performance of molybdenum blue in bright stock mineral oil.

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(See page 494 for a complete listing of the many interesting papers to be presented and an advance registration form)

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Abstracts from ASLE Transactions

D. F. Hays, "Plane Sliders of Finite Width"

An analytical solution to the problem of the lubrication of slider blocks of fixed wedge angle and finite width is presented. The method of solution is by the separation of variables which yields results conveniently shown in curve form illustrating the various slider properties. The analysis is not encumbered by the requirement of numerical or graphical methods of evaluation as in the case of Michell, and is similar in nature to the solutions of Muskat, Morgan and Meres wherein explicit analytical expressions are derived for the slider characteristics. The solutions appear in the form of convergent series.

The present analysis illustrates the manner by which the separation of variables in Reynold's Equation may be effected, completes the solution of the resulting eigenvalue problem, and shows the formulation of the expressions for load capacity, frictional resistance, center of pressure, coefficient of friction, and rates of flow. Typical pressure hills are shown as well as approximate flow patterns throughout the slider area.

A. M. Loeb and H. C. Rippel, "Determination of Optimum Proportions for Hydrostatic Bearings"

The effect of recess size on the pressure, flow and power requirements of several hydrostatic bearing configurations is described in terms of dimensionless coefficients called performance factors. Performance factors are determined analytically for a circular hydrostatic thrust bearing with a circular recess (for which there is a known solution), compared graphically with the electric analog solutions for this bearing and found to be in excellent agreement. The electric analog approach is also used to determine the performance factors of several other bearing configurations for which there are no known solutions. These data are presented in the form of dimensionless curves. It was found that for a given bearing configuration, there is a particular recess size which will give minimum supply pump power. Where limiting factors, such as pump output pressure and/or flow do not dominate, it is suggested that bearings be designed to operate at the minimum pump power point.

A. Cameron, "The Viscosity Wedge"

In a previous paper it was shown that a viscosity gradient across an oil film allowed a hydrodynamic load to be carried between contra rotating discs. If there is a temperature (and viscosity) gradient, not only through the oil film but also in the direction of motion, a considerable load can be borne. The equations are set up and solved numerically giving coefficient for oil film thickness and friction. The oil film thickness is comparable (three quarters) of that carried by Michell pads. The computed results are applied to the parallel surface thrust bearing described by Fogg in 1946 and shown to give tolerable agreement with the experimental findings.

A. Cameron and W. L. Wood, "Parallel Surface Thrust Bearing"

The theory for the thermal wedge thrust pad is given assuming (a) all the heat is taken away by the oil and (b) the viscosity is constant across the thickness of the film.

The viscosity is allowed to vary in the direction of motion.

Solutions are obtained by both analytical and relaxation methods for infinite finite pads. The viscosity is allowed to vary in the direction of motion and also a constant value is taken.

The results are displayed non-dimensionally graphically.

G. S. Reichenbach, J. B. Accinelli, and S. J. Beaubien, "Lubrication of High-Speed High-Temperature Thrust Ball Bearings"

High temperatures impose special problems on the operation of high speed axially loaded ball bearings. Among these are fatigue, lubricant deposits, and aggravated friction and surface damage at areas of metal contact. This paper is concerned only with the friction and surface damage aspects of the problem. Since a small scale bearing was to be used in the experimental work, and analysis was made of spinning, one of the major friction sources, the small-scale operating conditions were chosen to give ball-to-race surface temperatures approaching, as near as practical, the corresponding temperatures for full-scale bearings.

Bearing rig tests in a once-through jet lubrication system with silicone fluid, mineral oil, and a synthetic ester lubricant resulted in friction failures at approximately 350 F, 650 F, and 800 F, respectively. This is in agreement with full-scale experience and lends support to the validity of the rig tests. With oil-air mist lubrication, failure occurred at a much lower temperature. This was probably due to insufficient lubricant to provide for a hydrodynamic component of mixed friction at the contact zone or to a failure to provide any lubricant at all due to volatilization of the oil. Two EP additives used in mist lubricated systems did not give appreciable improvement probably because of the stainless steel test bearings. It was demonstrated that deposits from lubricant decomposition did not play a significant role in the above results and thus it could be concluded that the small scale rig emphasized the deposit-free high temperature friction properties of lubricants.

W. J. Anderson and T. L. Carter, "Effect of Lubricant Viscosity and Type on Ball Bearing Fatigue Life"

Two separate investigations were conducted to determine the effect of lubricants on the fatigue life of M-1 tool steel balls in the rolling contact fatigue spin rig. In the first investigation, four paraffinic mineral oils with viscosities of 5 to 113 centistokes at the 100F test temperature were used. Longer life was obtained with more viscous oil, life varying approximately as the 0.2 power of lubricant viscosity. In the second investigation of methyl silicone, a paraffinic, mineral oil, a sebacate, a water base glycol and an adipate, each of which had a viscosity of about 10 centistokes at the 100F test temperature, were used. The 10 per cent life was about 40 times as great with the silicone (best) as with the adipate (poorest). The life results correlated fairly well with the pressure viscosity characteristics as estimated from lubricants of the same base stocks.

A. Miller and A. A. Anderson, "Investigation of Oil Additives for Boundary Lubrication of Railroad Journal Bearings"

The boundary friction properties of the lubricated system of steel sliding on lead-

(*Cont. on p. 536*)

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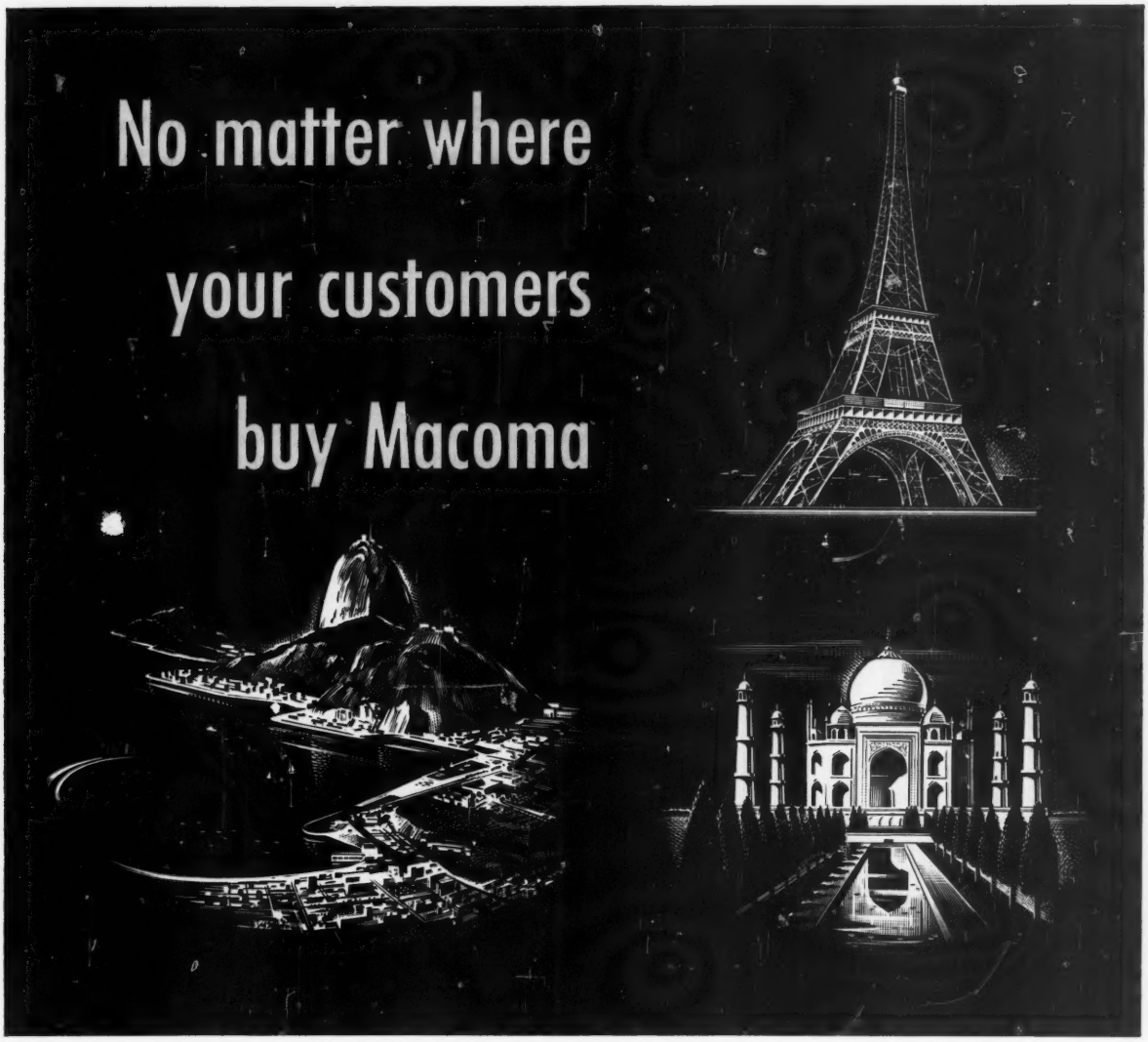

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Patent Abstracts

Compiled by Ann Burchick
Aluminum Co. of America

Lubricant, Patent #2,843,546 (W. Dietrich, F. Wetter and H. J. Mertens, assignors to Chemische Werke Huls Aktiengesellschaft) Lubricating composition comprising a lubricant vehicle consisting of mineral oil and about 1 per cent to 10 per cent by weight of a polyalkylene glycol xanthic acid derivative.

Organo-Metallic Compound And Lubricating Compositions Containing The Same, Patent #2,843,547 (T. W. Culmer, assignor to Hall Stewart) A lubricating composition comprising a hydrocarbon oil and from 0.02-0.10 per cent by weight of the oil of an organo-metallic compound having substantially the formula MoR_n wherein R is a member of the class consisting of phenyl groups, naphthyl groups, and alkyl substituted phenyl and naphthyl groups wherein each alkyl group has from one to four carbon atoms, and n is a small whole number of two-four, inclusive.

Rust Preventive Aviation Oil, Patent #2,843,548 (R. A. Westlund, Jr. and R. W. Scott, assignors to Esso Research & Engineering Co.) An aviation engine lubricant composition consisting essentially of about 79 wt. percent of a base oil, obtained by blending 60 per cent by weight of a dewaxed distillate mineral lubricating oil having a viscosity of 50 SSU at 210 F., and 40 per cent by weight of a dewaxed cylinder oil having a viscosity of about 210 SSU at 210 F.; about nine wt. percent of polyisobutylene having a molecular weight of approximately 14,000, the combination of said mineral lubricating oil and said polyisobutylene having a viscosity of about 115 SSU at 210 F.; about seven wt. percent of a microcrystalline wax having a melting point of about 189 F. obtained by deoiling petrolatum produced from solvent dewaxing of cylinder oils and bright stocks; and about five wt. percent of sorbitan monooleate.

Defoaming Composition, Patent #2,843,551 (F. J. Leonard, A. DeCastro and T. F. Groll, Jr., assignors to Nopco Chemical Co.) A defoaming composition consisting essentially of from about 40 percent to about 80 percent by weight of a liquid, aliphatic hydrocarbon having a boiling point of at least 150 F., from about three percent to about 12 percent by weight of an ester of a polyethylene glycol having a molecular weight which is greater than about 400 and an aliphatic carboxylic acid having a carbon chain length of from about 12 to 22 carbon atoms, from about 10 percent to about 20 percent by weight of an aliphatic carboxylic acid having a carbon chain length of from about 6 to 22 carbon atoms, from about one percent to about 10 percent by weight of a hydrocarbon soluble organo-polysiloxane having from 1 to 3 alkyl radicals per silicon atom, said radicals being selected from the group consisting of methyl, ethyl, propyl and butyl radicals, and the balance of the composition comprising substantially water.

Preparation of Phosphorus Sulfide-Hydrocarbon Reaction Products, Patent #2,843,579 (N. E. Lemmon, E. N. Roberts and A. R. Sabol, assignors to Standard Oil Co.) In the preparation of an oil soluble lubricant additive wherein a normally liquid hydrocarbon is reacted with from about one percent to about 50 percent of a phosphorus sulfide at a temperature of from about 200 F. to about 600 F. and the resultant reaction produce hydrolyzed at a temperature of from about 220 F. to about 500 F. whereby inorganic acids of phosphorus and low molecular weight organic acids of phosphorus are formed, the improvement comprising contacting said hydrolyzed reaction product at a temperature in the range of from about 100 F. to about 212 F. for a period of time sufficient to remove said acids of phosphorus formed by said hydrolysis, with from about 10 percent to about 200 percent by volume of a mixture consisting of water and from about five percent to about 95 percent by volume of a monohydroxy compound selected from the group consisting of phenol and alkyl alcohols having from 1 to about 5 carbon atoms, while monohydroxy compound has a solubility in water of at least about five percent by volume at the contacting temperature, and separating the hydrolyzed reaction product from said monohydroxy compound-water mixture.

High Molecular Weight Branched-Chain Ethers of Lubricating Grade, Patent #2,844,534 (D. L. Cottle, A. J. Mor-

way and D. W. Young, assignors to Esso Research & Engineering Co.) A lubricating grease comprising as a lubricating oil constituent a lubricating proportion of an ether of the general formula *R—O—R'*, wherein *R* and *R'* are the hydrocarbon radicals of Oxo alcohols having about 10 to 20 carbon atoms per molecule, said Oxo alcohol being an isomeric mixture of branched-chain alcohols produced by the catalytic carbonylation of olefins selected from the group consisting of polymers and copolymers of C_3 and C_4 olefins with CO and H_2 at temperatures of about 300 to 400 F., under pressures of about 2,500 to 4,000 psig., in the presence of a cobalt catalyst to form an aldehyde, followed by catalytic hydrogenation of said aldehyde to form said Oxo alcohol, and a grease thickening proportion of a grease thickener.

Alkaline Earth Metal Petroleum Mahogany Sulfonates, Patent #2,844,535 (M. Blumer, assignor to L. Sonneborn Sons, Inc.) Process for the production of oil solutions of basic alkaline earth metal petroleum mahogany sulfonates having low alkalinity, which comprises passing oxygen in contact with an anhydrous petroleum oil solution of an alkaline earth metal petroleum mahogany sulfonate containing a substantial quantity of a member selected from the group consisting of oxides and carbonates of said alkaline earth metal dispersed therein at a temperature of about 250-350 F. and continuing said contacting wits said oxygen for a period of time sufficient to produce an alkaline earth metal petroleum mahogany sulfonate of an alkaline earth metal content in excess of that contained in the normal alkaline earth metal petroleum mahogany sulfonate and of a substantially reduced alkalinity.

High Temperature Complex Grease Manufacturing Processes, Patent #2,844,536 (A. J. Morway, assignor to Esso Research & Engineering Co.) A process for the preparation of a high temperature lubricating grease composition wherein a major proportion of the lubricating oil in the final composition has not been subjected to high temperatures above about 350 F. which comprises the steps of forming at a temperature in the range of 450 to 500 F., a complex-thickened grease from a lubricating oil, an alkaline earth metal soap of a grease-making acid having in the range of 12 to 30 cargon atoms per molecule, and an alkaline earth metal salt of a monocarboxylic acid having in the range of 1 to 6 carbon atoms per molecule, with the mole ration of salt to soap being in the range of 10:1 to 50:1, admixing at a temperature in the range of 300 to 350 F. a minor amount of said complex-thickened grease with a major amount of simple soap grease formed from a lubricating oil and an alkaline earth metal soap of a grease-making acid having in the range of 12 to 30 carbon atoms per molecule, in proportion such that the mole ration of salt to soap in the finished formulation is in the range of 1:1 to 15:1 and the total salt-soap content thereof is in the range of five to 30 percent weight, and homogenizing the admixture to obtain the finished composition.

Homogeneous Lithium Base Lubricating Grease Compositions, Patent #2,844,537 (P. R. McCarthy and T. R. Orem, assignors to Gulf Research & Development Co.) A lubricating grease composition comprising a lubricating oil thickened to a grease with a lithium soap of a mixture of saturated, unsubstituted fatty acids having at least 12 carbon atoms, said mixture containing acids having at least 20 carbon atoms and acids having less than 20 carbon atoms, the ratio of acids having at least 20 carbon atoms to acids having less thon 20 carbon atoms ranging from 1:10 to 1:1.

Extreme Pressure Lubricant, Patent #2,844,538 (R. H. Krug and O. C. Elmer, assignors to The Texas Co.) An improved lubricant composition comprising a major amount of a base oil selected from the group consisting of mineral lubricating oils and polyesters of aliphatic carbaxylic acids and a minor amount of a compound.

Lubricating Composition, Patent #2,845,390 (P. M. Kerschner, assignor to Cities Service Research & Development Co.) A normally liquid lubricating composition comprising a major portion of a tetra ester of thiodi-itaconic acid.

Corrosion-Inhibiting Composition Containing Cetyl Dimethyl Amine Petroleum Sulfonates and Method, Patent #2,845,393 (C. W. Varvel, assignor to Phillips Petroleum Co.) A corrosion-inhibiting composition comprising a petroleum liquid containing from 10 to 300 p.p.m. of cetyl dimethylamine petroleum sulfonate derived from an oil soluble petroleum sulfonate.

Mold Lubricants for Glass, Patent #2,846,323 (P. Oppliger, assignor to Dow Corning Corp.) A mold release for glass consisting essentially of an oil-in-water emulsion of from .1 to 1 percent by weight methylpoly-siloxane fluid, from .1 to 2 percent by weight of paraffin oil, from .002 to .05 percent by weight colloidal graphite, emulsifying agent and the remainder being essentially water.

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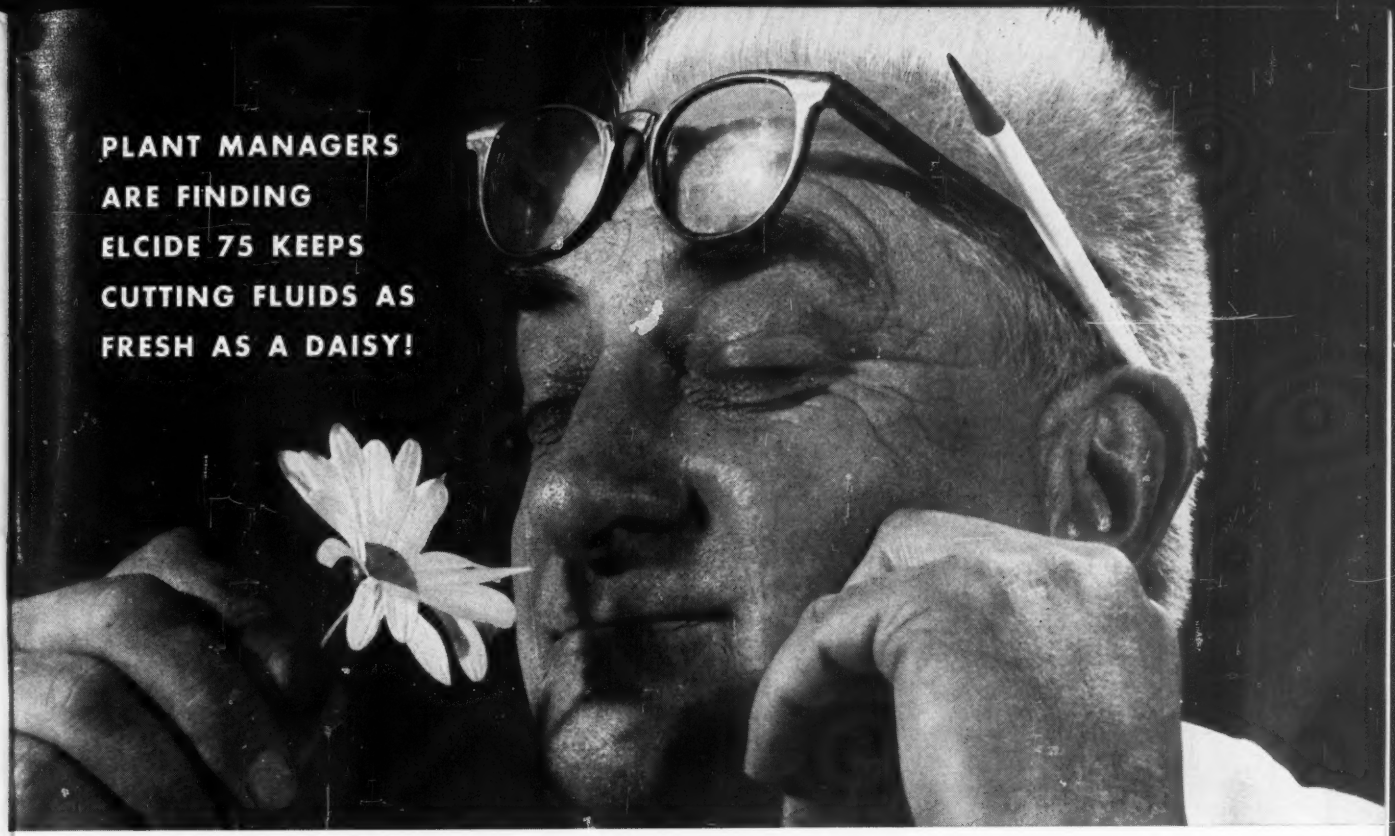

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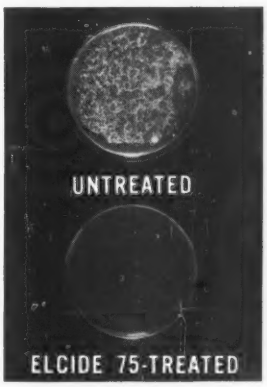

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TRANSACTIONS ABSTRACTS

(*Cont. from p. 528*)

base babbitt were investigated as a phase of the Association of American Railroads' sponsored project on freight car hot boxes. A friction pendulum was developed for determining the coefficients of boundary friction as a function of temperature with the specified metals lubricated with various lube oil additive blends.

A group of general relationships dealing with additives for the steel-babbit system was developed. It is concluded that the extreme pressure agents containing sulfur or chlorine are generally unsuited for railroad journal bearing use. Lubricity additives which function by simple physical adsorption were found to be ineffective at moderate or high temperatures existing in railroad operations. Those lubricity additives which chemisorb to metal surfaces and form a close-packed layer were found to be effective antifriction agents.

C. W. Cowley, C. J. Ultee, C. W. West, "Influence of Temperature on Boundary Lubrication"

The effects of temperature on the lubricity of a number of lubricants are studied. An apparatus designed to study lubricants under boundary conditions, with provisions for varying temperature, load, and speed, is described. Sharp transitions from smooth sliding to severe galling and seizure are observed at a specific temperature which is characteristic of the lubricant and the test conditions. These "failure temperatures" are useful in understanding the lubrication mechanism and in predicting lubricant performance.

J. R. McDowell, "Fretting of Hardened Steel in Oil"

To determine the effect of hardness on fretting wear, tests of AISI 4340 steel were made in an oil bath using a new machine designed to make fretting corrosion tests with a wide range of parameters. Hardness values from 258 to 743 Vickers were tested, the hardest specimen having a nitrided surface. The fretting action used, 0.005 in. reciprocating motion at pressures from 430 psi to 5840 psi, produced much less fretting than similar tests in air, with little or no oxide products resulting. The galled areas were measured for depth of pit and height of deposit with the results indicating some small effects due to hardness up to 460 Vickers. The nitrided specimens, however, produced smaller fretted areas and the roughening of their surfaces was shallow.

R. A. Kozlik, "Wear and Frictional Characteristics of Some Nickel-Base Alloys"

A test program was undertaken to determine the relative resistance to wear and galling of a variety of wrought and cast nicket-base alloys. Testing was done using a breakdown technique with a sliding velocity of 512 ft. per min. at the contact surfaces. The results showed that none of the wrought alloys tested were outstanding in their behavior when self-mated. However, mating with dissimilar alloys containing hard phases or soft phases possessing lubricating qualities effected substantial improvements in many instances. The use of chromium, molybdenum disulfide or sulfurized protective coatings was found to be feasible for inhibiting galling as long as their limitations were understood.

L. M. Niebylski, M. Antler, and L. O. Brockway, "Investigation of Wear by Electron Diffraction"

This review of electron diffraction theory and technique emphasizes its scope and limitations in the study of lubrication. The first section describes important areas of wear and friction studies where the electron diffraction method may be used, with examples chosen from the literature. Included in the discussion are: (a) monolayers, liquid lubricants, and greases, (b) polished and amorphous films, (c) the relation to wear of the crystallite size of surface phases, (d) possible relations between wear and the orientation of surface films, (e) solid lubricants. (f) mechanism of extreme pressure lubrication, and (g) the identification on wear debris.

The second part of the paper presents the electron diffraction results from three wear studies in the authors' laboratories.

Molybedenum isobutylxanthate is an effective extreme pressure oil additive for hard steel. Electron diffraction shows that the anti-wear mechanism may in part be due to the formation of a film containing iron monosulfide.

Cast iron top-piston-ring durability in a spark-ignition engine was studied using several fuels which gave widely different wear rates. The composition of the surface layers of worn rings possibly does not depend on fuel additive, but is dependent on test length. The degree of orientation of occluded graphite which has been smeared over the surface is primarily a function of wear rate.

Finally, preliminary studies suggest that there may be a relation between ring-bore wear and the crystallite size of the solids of combustion of fuel additives.

E. B. Sciulli and G. M. Robinson, "A Study of the Effect of Wear Particles and Adhesive Wear at High Contact Pressures"

The wear rate and friction characteristics were determined for certain combinations of cobalt base alloys and stainless steels when rubbed together at unit pressures up to 300,000 psi in an environment of demineralized water at room temperature. Wear rate and friction data were collected both in the presence and absence of wear particles. A study was also made on the effect of sliding-surface geometry in trapping wear particles.

The results suggest that an exponential relationship exists between wear rate and stress for the materials of test and this relationship is influenced by material combinations and sliding velocity. Entrapped wear particles also affect the wear rate.

Because the wear rate appears to increase sharply at some nominal contact stress when the data is plotted on Cartesian coordinates, the authors define an "Apparent Critical Stress," using this term and a wear factor term to aid in the evaluation and discussion of results.

N. B. Dewees, "Wear of Cobalt Base and Stainless Materials in High Purity Water"

Results of wear tests in clean water at room temperature and at 500F are presented. The differences in result with 0.08 in. diameter and line contact riders and with much larger riders are shown. The contact stress range is from 10 psi to 9000 psi for large contact areas and from 3000 psi to over 100,000 psi for small contact areas. The majority of the testing is at a linear velocity of about 2 in. per sec. The concept of wear per unit load and per unit distance traveled for a unit wear area is used for converting sliding wear data from various test machines to a common basis for comparison. The same concept can be used for calculating from wear data the expected wear in a new design. The range and trend of friction values encountered in some of the tests is presented.

E. H. Loeser, R. C. Wiquist and S. B. Twiss, "Cam and Tappet Lubrication. III—Radioactive Study of Phosphorus in the EP Film."

A radioactive tracer, phosphorus-32 synthesized into zinc dialkyl dithiophosphate molecules, was used to study the EP films formed by this motor oil additive on cast iron cams and tappets. The tightly bound films, which contain phosphorus and zinc, formed rapidly and then approached steady-state values in static and dynamic tests. The amount of film increased with oil temperature (200 to 300F) and with available surface area. Dynamic test conditions greatly increased the amount of film formed, indicating the marked effect of surface temperature, pressure or wear. The film is maintained on parts run in additive oil; moreover, the film was not easily worn off in non-additive oil. The chemical and physical properties of the films appeared to vary with the conditions of film formation.

(*Cont. on p. 540*)

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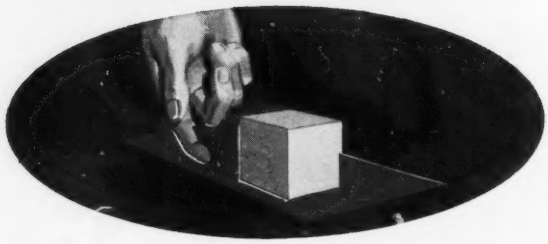
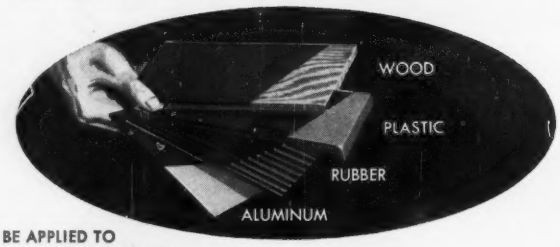


LOW COEFFICIENT OF FRICTION



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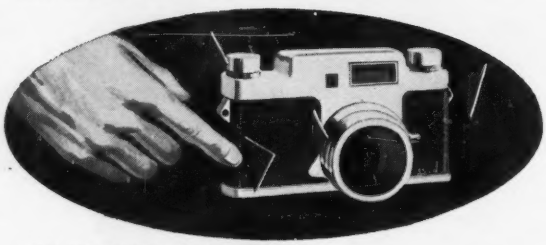

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Lubricants in the Forming of Aluminum

(*Cont. from p. 522*)

APPENDIX II

PHOSPHATE TREATMENT

CODE C.

1. Solution maintained at 125 F:
   (a) 1 pint of Code C liquid,
   (b) 3.7 oz of Code C powder,
   (c) In 4½ quarts of water;
   Treatment for 2 minutes.
2. Rinsing—two procedures were followed:
   (a) Water rinse after treatment 1; or
   (b) Without rinsing after treatment 1.
3. Drying—two procedures were followed:
   (a) Oven dried at 280 to 350 F for 2 minutes; or
   (b) Air dried

CODE D.

1. Solution maintained at 130 F:
   (a) 320 ml of Code-D liquid,
   (b) 68 grams of boric acid,
   (c) 9 grams of ferrous sulfate,
   (d) in 3875 ml water;
   Treatment for 5 mintes.
2. Water rinse and air-dry.

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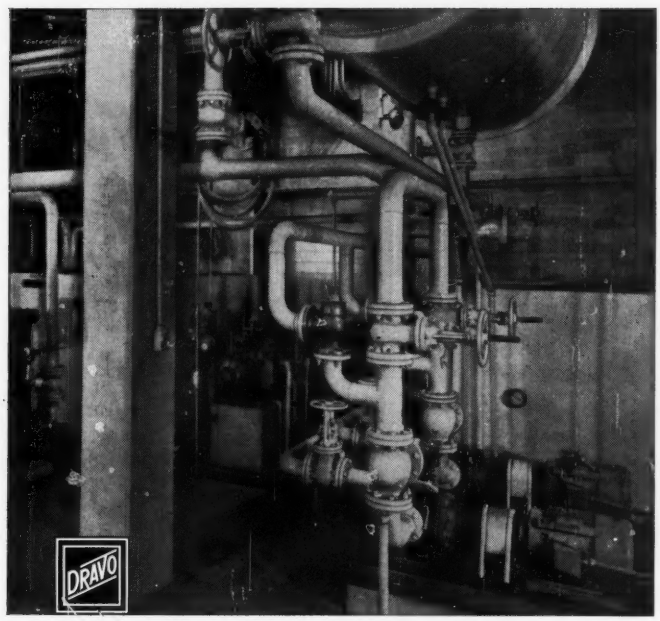
DRAVO-DeLAVAL Lubrication Systems for Bowaters



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Radioactive counting was used to determine the film on tappets and the thermal stability of the compounded oil. Autoradiographs showed the concentration and distribution of the film on cams and tappets.

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M. C. Shaw and P. A. Smith, "Workpiece Compatibility of Ceramic Cutting Tools"

It is now well known that certain types of cemented carbides give excellent results when used to cut cast irons but poor results when used to cut steels and vice versa. This relative ability of a given tool material to perform well when cutting a given workpiece material is referred to here as compatibility.

Ceramic metal cutting tools have been in use in machining metals such a short time that it is not yet generally known on which materials these tools can be used to best advantage. In this report the performance of ceramic and cemented carbide tools is compared when machining a wide variety of metals. It is found that there are certain metals for which either the surface chemical or thermal characteristics of ceramic tools are particularly advantageous.

The report is concluded by a table which lists a large number of ferrous and nonferrous metals in order of decreasing compatibility with aluminum oxide tools.

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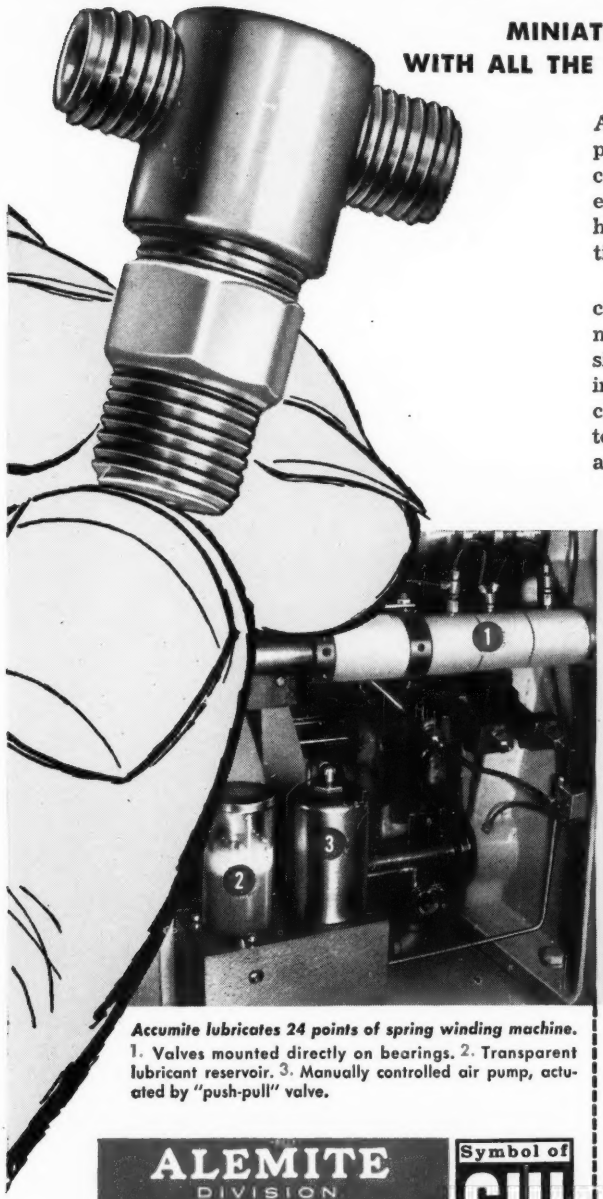

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